CWM PO*WW*ER™
Evaporation-Catalytic Oxidation Technology

Applications Analysis Report

Printed on Recycled Paper

Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized by the 1986 Superfund Amendments and Reauthorization Act (SARA). The SITE program is a joint effort between the EPA Office of Research and Development (ORD) and the Office of Solid Waste and Emergency.Response (OSWER). The purpose of the program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites through field technology demonstrations designed to provide performance and cost data on selected technologies.

A field demonstration was conducted under the SITE program to evaluate the Chemical Waste Management, Inc. (CWM), PO*WW*ER™ technology. The technology demonstration took place at CWM's Lake Charles Treatment Center (LCTC) site in Lake Charles, Louisiana. The purpose of the demonstration effort was to obtain information on the performance and cost of the technology and to assess its use at this and other uncontrolled hazardous waste sites. Documentation of the demonstration consists of two reports: (1) a Technology Evaluation Report, which describes field activities and laboratory results; and (2) this Applications Analysis Report, which interprets the demonstration data and discusses the technology's potential applicability.

A limited number of copies of this report will be available at no charge from the EPA Center for Environmental Research Information, 26 West Martin Luther Ring Drive, Cincinnati, Ohio 45268. Requests for this report should include the EPA document number on the report's cover. When the limited supply is exhausted, additional copies may be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia 22161, telephone number (703) 487-4600. Reference copies of this report will be available at EPA libraries as part of the Hazardous Waste Collection. Information about the availability of reports can be obtained by calling ORD Publications in Cincinnati, Ohio, at (513) 569-7562.

E. Timothy Oppelt, Director

Risk Reduction Engineering Laboratory

Abstract

This report **evaluates** the Chemical Waste Management, Inc. (CWM), PO*WW*ER™ technology's ability to remove volatile organic compounds (VOC), semivolatile organic compounds (SVOC), ammonia, cyanide, metals, and other inorganic contaminants from aqueous wastes. This evaluation is based on treatment performance and cost data obtained from the Super-fund Innovative Technology Evaluation (SITE) demonstration and 11 case studies conducted by CWM.

The PO*WW*ER™ system reduces the volume of an aqueous waste and catalytically oxidizes volatile contaminants. The PO*WW*ER™ system consists primarily of (1) an evaporator that reduces influent wastewater volume, (2) a catalytic oxidizer that oxidizes the volatile contaminants in the vapor stream from the evaporator, (3) a scrubber that removes acid gases formed during oxidation, and (4) a condenser that condenses the vapor stream leaving the scrubber.

The PO*WW*ER™ system demonstration was conducted under the SITE program at CWM's Lake Charles Treatment Center (LCTC) site in Lake Charles, Louisiana. The SITE demonstration was conducted in September 1992. During the demonstration, the PO*WW*ER™ system treated landfill leachate, an F039 hazardous waste, contaminated with VOCs, SVOCs, ammonia, cyanide, metals, and other inorganic contaminants. During the development of the PO*WW*ER™ system, CWM conducted bench- and pilot-scale tests and collected treatability data for the following aqueous wastes: (1) landfill leachate, (2) contaminated well water, (3) contaminated lagoon water, (4) fuels decant water, (5) **oil emulsion** wastewater, and (6) wastewater contaminated with nitrogen-containing organic compounds and cyanide. During these tests, the PO*WW*ER™ system processed aqueous wastes containing VOCs, SVOCs, pesticides, herbicides, solvents, heavy metals, cyanide, ammonia, nitrate, chloride, and sulfide.

Based on the results of the SITE demonstration and other case studies, the following conclusions can be drawn:

- The PO*WW*ER™ system can process a wide variety of aqueous wastes with differing contaminant concentrations.

- During the SITE demonstration, the PO*WW*ER™ system achieved a total solids (TS) concentration ratio of about 32 to 1. During other case studies conducted by CWM, a TS concentration ratio ranging from 35 to 1 to 50 to 1 was achieved.

- During the SITE demonstration, the TS concentration in the brine ranged from 50 percent to 56 percent. During other case studies conducted by CWM, the TS concentration in the brine ranged from 28 to 80 percent.

. Concentrations of VOCs and SVOCs in the product condensate exiting the PO*WW*ER™ system condenser were below their respective detection limits of 5 to 10 ug/L and 10 to 130 ug/L.

Abstract (continued)

- During the SITE demonstration, ammonia and cyanide concentrations in the product condensate samples were below the detection limits of 0.1 and 0.01 mg/L, respectively. Results from other case studies show that the product condensate contained ammonia and cyanide at similar low concentrations.

- The product condensate contained trace levels of metals.

- The product condensate may contain nitrate resulting from the hydrolysis of nitrogen dioxide.

- During the SITE demonstration, the brine, which is an F039-derived hazardous waste, was also found to be hazardous based on toxicity characteristic leaching procedure (TCLP) test results. The brine also had relatively high levels of cyanide. Under acidic conditions, the brine could exhibit the hazardous waste characteristic of reactivity.

- During the SITE demonstration, the noncondensible gas stream met proposed regulatory requirements for the LCTC site. The noncondensible gas emissions may contain VOCs, SVOCs, ammonia, cyanide, nitrogen oxides (NOx), sulfur dioxide (SO,), carbon monoxide (CO), and carbon dioxide (CO,), generally at low concentrations determined by treatment conditions and the type of contaminants present in the feed waste.

- The PO*WW*ER™ system removes sources of feed waste toxicity, such as VOCs, SVOCs, ammonia, and cyanide. The feed waste was acutely toxic, with LC50s consistently below 10 percent. The product condensate was nontoxic, with LC50s consistently greater than 100 percent, but only after the product condensate was cooled and its pH, dissolved oxygen level, and hardness or salinity were increased to meet demonstration objectives and as allowed in EPA acute toxicity testing procedures.

- Economic data indicate that the capital cost for a 50-gallon per minute PO*WW*ER™ system is approximately $4 million on a turnkey basis. The capital cost includes treatability study costs; design costs; all necessary components of a PO*WW*ER™ system; all interconnecting piping, controls, and monitoring equipment; and assembly and installation costs. Annual operating and maintenance (O&M) costs, including labor, consumables, utilities, analytical services, and waste disposal costs at a Superfund site are estimated to be about $3.3 million. Waste disposal costs account for about 70 percent of the annual cost. The total cost of a project lasting 15 years was estimated to be about $100 per 1000 gallons of aqueous waste treated; and the total cost of a project lasting 30 years was estimated to be about $73 per 1,000 gallons of aqueous waste treated.

This report also discusses the applicability of the PO*WW*ER™ system based on compliance with regulatory requirements, implementability, short-term impact, and long-term effectiveness. In addition, factors influencing the technology's performance in meeting these criteria and evaluation limitations are discussed.

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Acronyms, Abbreviations, and Symbols

μg	Microgram
μg/L	Micrograms per liter
ACL	Alternate concentration limits
AEA	Atomic Energy Act
ARAR	Applicable or relevant and appropriate requirement
ARI	ARI Technologies, Inc.
BPR	Boiling point rise
Btu	British thermal unit
CAA	Clean Air Act
CEM	Continuous emissions monitoring
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CN⁻	Cyanide
CO	Carbon monoxide
CO_2	Carbon dioxide
CWA	Clean Water Act
CWM	Chemical Waste Management, Inc.
dscm	Dry standard cubic meter
DOE	Department of Energy
EP	Extraction procedure
EPA	U.S. Environmental Protection Agency
ES	Engineering-Science, Inc.
ft	Foot
ft^2	Square feet
ft^3	Cubic feet
gal.	Gallon
gpd	Gallons per day
gph	Gallons per hour
gpm	Gallons per minute
gr	Grain
HCl	Hydrochloric acid
HCN	Hydrogen cyanide
in.	Inch
kg	Kilogram
kg/cm^2	Kilogram per square centimeter
kJ	Kilojoule
km	Kilometer
kWh	Kilowatt-hour
L	Liter
lb	Pound
lb/hr	Pounds per hour

Acronyms, Abbreviations, and Symbols (continued)

LCTC	Lake Charles Treatment Center
LC50	Median lethal concentration
LDR	Land Disposal Restrictions
m	Meter
m^2	Square meters
m^3	Cubic meters
MCL	Maximum contaminant level
mi	Mile
mg	Milligram
mg/L	Milligrams per liter
MJ	Megajoule
N_2	Nitrogen
NH_3-N	Ammonia nitrogen
NH_4^+	Ammonium ion
NO_x	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
O_2	Oxygen
O&M	Operation and maintenance
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene
PIC	Product of incomplete combustion
POTW	Publicly owned treatment works
PPE	Personal protective equipment
ppm	Parts per million
ppmv	Parts per million by volume
PRC	PRC Environmental Management, Inc.
psi	Pounds per square inch
QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act
scfh	Standard cubic feet per hour
scfm	Standard cubic feet per minute
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
SO_2	Sulfur dioxide
SVOC	Semivolatile organic compound
TCE	Trichloroethene
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TS	Total solids
TSS	Total suspended solids

Acronyms, Abbreviations, and Symbols (continued)

TNMHC   Total nonmethane hydrocarbon concentration
TOC   Total organic carbon
TOX   Total organic halides
TSCA   Toxic Substances Control Act
UIC   Underground injection control
UST   Underground Storage Tank
Versar   Versar, Inc.
VOC   Volatile organic compound
VOST   Volatile organic sampling train
WET   Whole effluent toxicity

Conversion Factors

	English	x	Factor	=	Metric
Length:	1 inch (in.)	x	2.54	=	centimeter (cm)
	1 foot (ft)	x	0.305	=	meter (m)
	1 mile (mi)	x	1.61	=	kilometer (km)
Area:	1 square foot (ft^2)	x	0.0929	=	square meter (m^2)
Volume:	1 gallon (gal.)	x	3.78	–	liter (L)
	1 cubic foot (ft^3)	x	0.0283	–	cubic meter (m^3)
Mass:	1 grain (gr)	x	64.8	=	milligram (mg)
	1 pound (lb)	x	0.454	=	kilogram (kg)
	1 ton (t)	x	907	=	kilogram (kg)
Pressure:	1 pound per square inch (psi)	x	0.0703	=	kilogram per square centimeter (kg/cm^2)
Energy:	1 British Thermal Unit (Btu)	x	1.05	=	kilojoule (kJ)
	1 kilowatt hour (kWh)	x	3.60	=	megajoule (MJ)
Temperature:	($^\circ$F - 32)	x	0.556	=	$^\circ$C

Acknowledgements

Section 1
Executive Summary

This report summarizes the findings of an evaluation for the PO*WW*ER™ technology developed by Chemical WasteManagement, Inc. (CWM). This study **was conducted** under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. A series of demonstration tests of the technology were performed by EPA as part of this program. The demonstration tests were conducted in September 1992 at the CWM Lake Charles Treatment Center (LCTC) site in Lake Charles, Louisiana. The evaluation of the PO*WW*ER™ technology was based on the results of the SITE demonstration and 11 case studies performed by CWM for several private clients.

The PO*WW*ER™ technology reduces the volume of an aqueous waste and catalytically oxidizes volatile contaminants. The PO*WW*ER™ system consists primarily of (1) an evaporator that reduces influent wastewater volume, (2) a catalytic oxidizer that oxidizes the volatile contaminants in the vapor stream from the evaporator, (3) a scrubber that removes acid gases formed during oxidation, and (4) a condenser that condenses the vapor stream leaving the scrubber. Conclusions drawn and results of the SITE demonstration tests and case studies are summarized below.

1.1 Conclusions

Based on the SITE demonstration and several other case studies, the conclusions presented below may be drawn on the applicability of the PO*WW*ER™ system.

- The PO*WW*ER™ system can process a wide variety of aqueous wastes with differing contaminant concentrations. Bench- and pilot-scale tests effectively treated aqueous wastes such as (1) landfill leachate, (2) contaminated well water, (3) contaminated lagoon water, (4) fuels decant water, (5) oil emulsion wastewater, and (6) wastewater contaminated with nitrogen-containing organic compounds and cyanide. During

these tests, the PO*WW*ER™ system effectively treated aqueous wastes containing volatile organic compounds (VOC), semivolatile organic compounds (SVOC), pesticides, herbicides, solvents, heavy metals, cyanide, ammonia, nitrate, chloride, and sulfide.

- During aqueous waste treatment in the PO*WW*ER™ system, all volatile contaminants present are vaporized depending on the relative volatility of each compound and the waste mixture. Contaminant removal mechanisms in the PO*WW*ER™ system include evaporation, catalytic oxidation, and absorption in a scrubber, if required. Contaminants that do not vaporize concentrate in the brine.

- The PO*WW*ER™ system evaporates VOCs and certain SVOCs from the feed waste. As expected, VOC evaporation efficiencies are greater than SVOC removal efficiencies. Among SVOCs, compounds with lower boiling points and higher vapor pressures have higher evaporation efficiencies than compounds with higher boiling points and lower vapor pressures.

- Brine wasted from the PO*WW*ER™ system is not treated on site and requires off-site treatment by stabilization and disposal. When process wastewater is treated in the PO*WW*ER™ system, brine characteristics may be suitable for brine to be reused or recycled.

- Ammonia and cyanide evaporation efficiencies are a function of the feed waste pH and the type of metal ions present in the feed waste. Depending on the type of metals present and the feed waste pH, ammonia and cyanide may be either free or complexed. Free ammonia evaporation efficiency increases at pH values greater than 9, while free

cyanide evaporation efficiency increases at pH values less than 9.

- The quality of the product condensate does not vary with feed waste characteristics and total contaminant loading at the levels measured during the SITE demonstration. However, total contaminant loading may affect the contaminant evaporation efficiency, which in turn affects the contaminant concentrations in the brine. Contaminant loading may also result in slight increases in the concentrations of contaminants in the noncondensible vent gas.

- The PO*WW*ER™ system removes sources of feed waste toxicity. The feed waste was acutely toxic with LC50s consistently below 10 percent. The product condensate was nontoxic with LC50s consistently greater than 100 percent, but only after the product condensate was cooled and its pH, dissolved oxygen level, and hardness or salinity were increased, to meet demonstration objectives and as allowed in EPA acute toxicity testing procedures.

- The PO* WW *ER™ system operated reliably during the SITE demonstration. However, some minor operational problems with the PO*WW*ER™ system were observed during shakedown and startup operations. Operational problems resulted from an electrical power outage and brine sampling line clogging.

- Factors affecting the performance of the oxidizer include: (1) oxidizer temperature, (2) percent excess oxygen (O_2), and (3) oxidizer residence time.

- According to CWM, the catalyst used in the PO*WW*ER™ system oxidizer is a proprietary nonprecious metal oxide catalyst that withstands fouling, activity suppression, and poisoning. Also, according to CWM, the catalyst requires periodic make-up to replace attrition losses.

- During treatment of aqueous wastes in the PO*WW*ER™ system, total solids (TS) concentration ratios ranging from 32 to 1 to 50 to 1 can be achieved. TS concentrations in the brine may range from 28 to 80 percent.

- The evaporator boiling point is an important operating parameter for the PO*WW*ER™ system because it determines contaminant removal efficiencies. The evaporator boiling point corresponds to a specific BPR, which depends on the TS concentration in the brine.

- The physical-chemical characteristics of the brine may have a fouling effect on heat transfer surfaces. Periodic system cleaning may be required to maintain high heat transfer coefficients.

- The PO*WW*ER™ technology can effectively treat concentrated as well as dilute wastewaters. For dilute wastewaters volume reduction will be greater and the energy consumption per unit volume of feed wastewater will be higher. However, as a result, less brine will be produced and disposal costs will be lower.

- For some applications, the PO*WW*ER™ system may need to be constructed of corrosion resistant material.

- Treatability studies are recommended when large-scale applications of the technology are considered. Preliminary treatability studies may help determine approximate process rates and feed waste adjustments required, allowing an assessment of the PO*WW*ER™ system's applicability for a specific site waste. Treatability studies can also determine whether final product condensate polishing treatment is required to meet discharge requirements.

1.2 Results

This section summarizes the results of the PO*WW*ER™ system's performance during the SITE demonstration and during several case studies conducted by CWM for private clients. The SITE demonstration was conducted using a pilot-scale (pilot) PO*WW*ER™ plant at CWM's LCTC site. Observations made during the SITE demonstration should be used with critical engineering judgement when projecting full-scale PO*WW*ER™ system performance.

During the SITE demonstration, the evaluation of the PO*WW*ER™ system was restricted by testing limitations imposed by CWM for protection of proprietary know-how. Therefore, the following parameters were not evaluated

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during the SITE demonstration: (1) oxidation efficiency, (2) boiling point rise, (3) heat transfer coefficients, (4) brine characteristics (for the determination of thermal by-product formation), and (5) scrubber blowdown characteristics.

During the SITE demonstration, the PO*WW*ER™ system treated landfill leachate, an F039 hazardous waste, contaminated with VOCs, SVOCs, ammonia, cyanide, metals and other inorganic contaminants. The SITE demonstration was conducted under one set of operating parameters, which were established by CWM based on past experience with the PO*WW*ER™ system. These operating parameters were applied in two sets of test runs: one set of three replicate test runs using unspiked LCTC landfill leachate and one set of three replicate test runs using LCTC landfill leachate spiked with VOCs, SVOCs, and metals. Each demonstration test required about 9 hours of PO*WW*ER™ system operation in order to conduct sampling and monitoring. During the tests, landfill leachate was processed at an average rate of 0.18 gallons per minute (gpm). Key findings of the SITE demonstration at the LCTC site are presented below.

- The ability of the PO*WW*ER™ system to concentrate aqueous wastes was evaluated by the volume reduction and concentration ratio achieved. Brine was wasted and sampled only once during each 9-hour test run, although the PO*WW*ER™ system operated continuously. The volume of brine wasted and sampled during each 9-hour test period consisted of about 5 percent of the feed waste volume processed during the 9-hour period. The concentration ratio, defined as the ratio of TS concentration in the brine over the TS concentration in the feed waste, was about 32. The TS concentration in the brine ranged from 50 to 56 percent.

- The feed waste contained average concentrations of critical VOCs ranging from 350 to 110,000 micrograms per liter (µg/L); critical SVOCs ranging from 6,000 to 23,000 µg/L; ammonia ranging from 140 to 160 milligrams per liter (mg/L); and cyanide ranging from 24 to 33 mg/L. No VOCs, SVOCs, ammonia, or cyanide were detected in the product condensate.

- The noncondensible gas vent emissions had the following characteristics: (1) the average carbon monoxide (CO) emission rates ranged from 1.1 $\times 10^{-3}$

to 3.92x10^{-3} pounds per hour (lb/hr); (2) the average sulfur dioxide (SO$_2$) emission rates were less than 5.5x10^{-4} lb/hr; and (3) the average nitrogen oxide (NO$_x$) concentrations emission rates ranged from 3.46x 10^{-2} to 5.03x10^{-2} lb/hr. The noncondensible vent gas emissions for these parameters met the proposed regulatory requirements for the LCTC site.

- The PO*WW*ER™ system removes sources of feed waste toxicity. The feed waste was acutely toxic, with median lethal concentrations (LC50) consistently below 10 percent. The product condensate was nontoxic, with LC50s consistently greater than 100 percent, but only after the product condensate was cooled and its pH, dissolved oxygen level, and hardness or salinity were increased, to meet demonstration objectives and as allowed in EPA acute toxicity testing procedures.

- Economic data indicate that the capital cost for a 50-gpm PO*WW*ER™ system is approximately $4 million on a turnkey basis. The capital cost includes treatability study costs; design costs; all necessary components of a PO*WW*ER™ system; all interconnecting piping, controls, and monitoring equipment; and assembly and installation costs. Annual operating and maintenance (O&M) costs, including labor, consumables, utilities, analytical services, and waste disposal costs at a Superfund site are estimated to be about $3.3 million. Waste disposal costs account for about 70 percent of the annual costs. The total treatment cost of a project lasting 15 years was estimated to be about $100 per 1,000 gallons of aqueous waste treated; and the total cost of a project lasting 30 years was estimated to be about $73 per 1,000 gallons of aqueous waste.

Key findings from 11 other case studies conducted by CWM for several private clients are presented below.

- In six case studies, landfill leachate spiked with VOCs, SVOCs, ammonia, and cyanide was treated in the PO*WW*ER™ system pilot plant. The results show that a TS concentration ratio ranging from 38 to 1 to 40 to 1 was achieved. All of the spiking VOCs were effectively evaporated from the brine. Only the SVOCs originally present, or added to the landfill leachate during spiking, remained. Oxidation efficiencies of greater than

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99 percent were achieved for all spiking VOCs. Ammonia was effectively evaporated from the brine. At pH 11, the ammonia evaporation efficiency was significantly higher than at approximately pH 7 or 8. Ammonia oxidation was more effective at higher temperatures than at lower temperatures. In the product condensate, both metals and organics were removed to below National Pollutant Discharge Elimination System (NPDES) storm water discharge limits without further treatment.

In the seventh case study, contaminated lagoon water was treated in the **PO*WW*ER**™ system pilot plant. A concentration ratio of 50 to 1 was achieved. The oxidation efficiency ranged from 90 to 97 percent.

In the eighth case study, fuels decant water was treated. A concentration ratio of 42 to 1 was achieved in the evaporator. The TOC removal efficiency was greater than 99 percent.

In the ninth case study, well water spiked with cyanide at 139 mg/L was treated. The well water was acidified to cause the release of hydrogen cyanide (HCN) gas. Cyanide was evaporated from the brine to below detection limits. The cyanide level in the product condensate was also below detection limits.

- In the tenth case study, oil emulsion wastewater was treated in a bench-scale system. The concentration ratio achieved was 35 to 1. The oxidized product condensate contained 0.1 mg/L ammonia, 55 mg/L chloride, and had a pH of 3.1.

- In the eleventh case study, wastewater contaminated with nitrogen-containing organic compounds and cyanide was treated in the **PO*WW*ER**™ pilot plant. The cyanide removal efficiencies ranged from 96.9 to 99.99 percent. Cyanide oxidation efficiencies ranged from 93.5 to 99.96 percent. Ammonia removal efficiencies ranged from 91.6 to greater than 99.6 percent. Ammonia oxidation efficiencies ranged from 83.8 to greater than 99.6 percent. Brine TS concentration ranged from 28 to 80 percent.

Section 2
Introduction

This section provides background information on the purpose, history, and goals of the Superfund Innovative Technology Evaluation (SITE) program; discusses documentation of the **SITE** demonstration results; describes the **PO*WW*ER™** technology developed by Chemical Waste Management, Inc. (CWM); discusses innovative features and limitation of the **PO*WW*ER™** technology; and provides a list of key contacts.

2.1 Purpose, History, and Goals of the SITE Program

The SITE program is a unique international effort dedicated to advancing the development, evaluation, and implementation of innovative treatment technologies applicable to hazardous waste sites. The SITE program was established in response to the 1986 Superfund Amendments and Reauthorization Act (SARA), which recognized the need for an alternative or innovative treatment technology research and development program. The SITE program is administered by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) Risk Reduction Engineering Laboratory (RREL).

The SITE program consists of four component programs: (1) the Demonstration Program, (2) the Emerging Technology Program, (3) the Monitoring and Measurement Technologies Program, and (4) the Technology Transfer Program. This Applications Analysis Report was produced as part of the SITE Demonstration Program. The objective of the Demonstration Program is to provide reliable performance and cost data on innovative technologies so that potential users can assess a technology's suitability for specific site cleanups. To produce useful and reliable data, demonstrations are conducted at hazardous waste sites or under conditions that closely simulate actual waste and site conditions.

Data collected during a demonstration are used to assess the performance of the technology, the potential need for pretreatment and post-treatment processing of the waste, treatable types of waste and media, potential operating problems, and approximate capital and operating costs. Demonstration data can also provide insight into a technology's long-term operating and maintenance (O&M) costs and long-term application risks.

Technologies are selected for the SITE Demonstration Program primarily through annual requests for proposals. Proposals are reviewed by ORD staff to determine which technologies are most promising **for** use at hazardous waste sites. To be eligible, technologies must be developed to the pilot- or full-scale stage, must be innovative, and must offer some advantage over existing technologies. Mobile technologies are of particular interest.

Cooperative agreements between EPA and the developer determine responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected **to** pay the **costs** of transporting, operating, and removing its equipment. EPA is responsible for project planning, sampling and analysis, quality assurance (QA), quality control (QC), preparing reports, and disseminating information.

Each SITE demonstration provides information necessary to evaluate the performance of a technology in treating a particular waste at the demonstration site. To obtain data with broad applications, EPA and the technology developer try to choose a waste frequently found at other contaminated sites. In many cases, however, waste characteristics at other sites will differ in some way from the waste tested. Thus, a successful demonstration of the technology at one site does not ensure that it will work as well at other sites. Data obtained from the SITE demonstration may have to be extrapolated and combined with other information about the technology to estimate site-specific operating ranges and limits of the technology.

2.2 Documentation of the SITE Demonstration Results

The results of each SITE demonstration are presented in two documents, the Technology Evaluation Report and the Applications Analysis Report, each with a distinct purpose. These documents are described below.

2.2.1 *Technology Evaluation Report*

The Technology Evaluation Report provides a comprehensive description of the SITE demonstration and its results. It is intended for engineers making a detailed evaluation of the technology's performance for the demonstration site and waste situation. These technical evaluators seek to understand, in detail, the performance of the technology during thedemonstration and the advantages, risks, and costs of the technology for a specific application. The report also provides a detailed discussion of QA and QC measures followed during the demonstration.

2.2.2 *Applications Analysis Report*

To encourage wider use of technologies demonstrated under the SITE program, the Applications Analysis Report provides information on a technology's costs and its applicability to other sites and wastes. Before a SITE demonstration is conducted, the amount of data available for an innovative technology may vary widely. Data may range from limited laboratory tests on synthetic wastes to performance data on actual wastes treated in pilot- or full-scale treatment systems. The Applications Analysis Report synthesizes available information on the technology and draws reasonable conclusions about its broad-range applicability. This report is intended for those considering a technology for hazardous site cleanups; it represents a critical step in the development and commercialization of a treatment technology.

The principal use of the Applications Analysis Report is to assist in determining whether a technology should be considered further as an option for a particular cleanup situation. The Applications Analysis Report is intended for decision makers responsible for implementing remedial actions. The report discusses advantages, disadvantages, and limitations of the technology. Costs for different applications may be estimated using 12 cost categories based on available data from pilot- and full-scale applications. The report also discusses specific factors, such as site and waste characteristics, that may affect performance and cost.

2.3 Technology Description

The PO*WW*ER™ technology can be applied to reduce the volume of an aqueous waste and to catalytically oxidize volatile contaminants. Figure 2-l shows a flow diagram of the PO*WW*ER™ pilot-scale (pilot) plant. The PO*WW*ER™ system consists primarily of an evaporator to reduce the influent wastewater volume, a catalytic oxidizer to oxidize the volatile contaminants in the vapor stream from the evaporator, a scrubber to remove acid gases produced during oxidation, and a condenser to condense the vapor stream leaving the scrubber.

The following sections describe the individual components of the LCTC PO*WW*ER™ pilot plant including: (1) the feed system, (2) the evaporator, (3) the catalytic oxidizer, (4) the scrubber, and (5) the condenser.

2.3.1 Feed System

Wastewater to be treated by the PO*WW*ER™ pilot plant at the LCTC site is delivered to the plant by a tanker truck. Wastewater is pumped from the tanker truck through a hose into the 500-gallon stainless steel feed tank. The feed pump, which is gravity fed from the tank, pumps the feed to the evaporator. The amount of wastewater in the tank is determined by a level indicator on the side of the feed tank. The feed tank is also equipped with an agitator mounted on the top of the tank to mix additives into the wastewater (feed waste). To control foaming in the vapor body, an antifoaming agent can either be added to the wastewater in the feed tank or injected directly into the vapor body. The feed waste pH is monitored and adjusted in the feed tank before being treated in the evaporator. The feed rate depends on the type of waste to be treated.

2.3.2 Evaporator

The first step in the PO*WW*ER™ process is volume reduction, which is achieved through evaporation. All volatile compounds are vaporized depending on the relative volatility of each compound and the composition of the feed waste. The PO*WW*ER™ technology utilizes this lack of specificity to treat complex wastewater mixtures.

The evaporator consists of three main pieces of equipment: the heat exchanger, the vapor body, and the entrainment separator. As feed waste is pumped to the evaporator, it combines with heated process liquor. The liquid waste is then further heated in a vertical tube heat exchanger, which has two passes, four tubes per
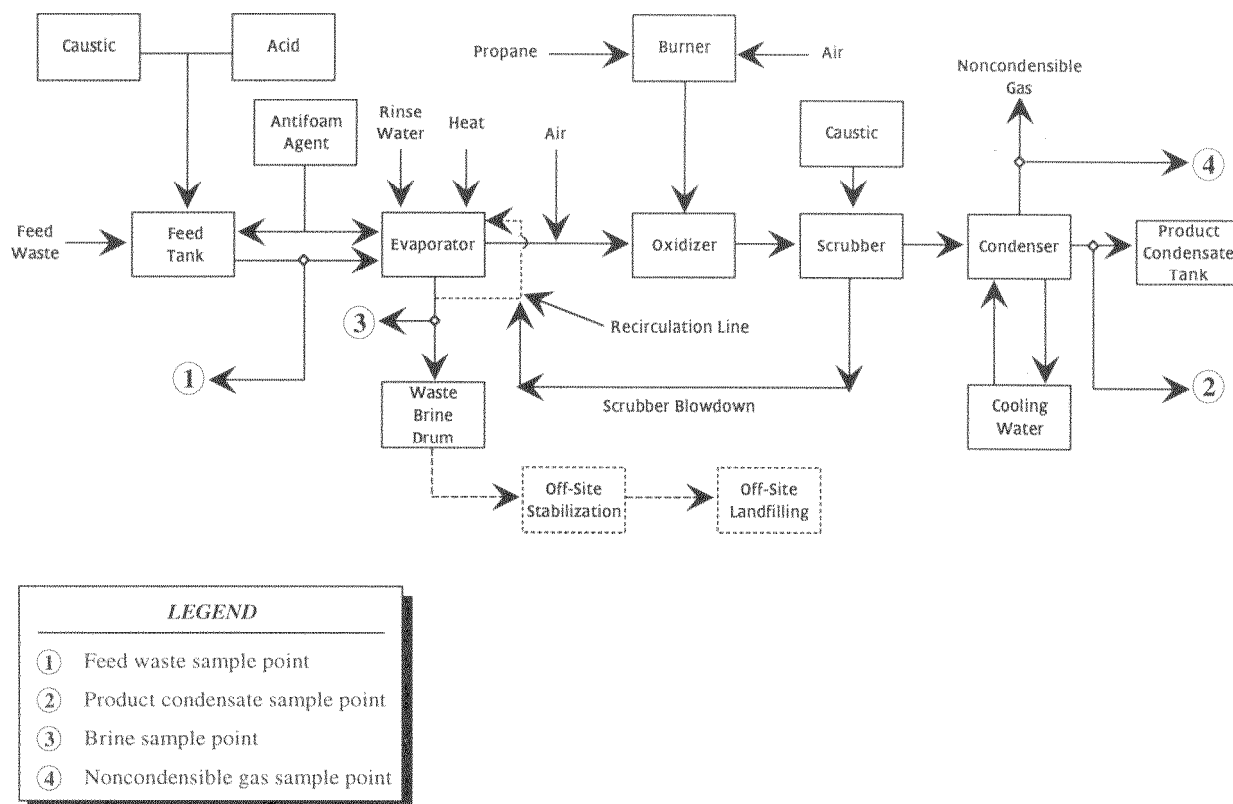
Figure 2-1. PO*WW*ER™ pilot plant flow diagram

LEGEND

1. Feed waste sample point
2. Product condensate sample point
3. Brine sample point
4. Noncondensible gas sample point

pass. Heat is supplied by steam generated in a boiler. Liquid waste flows through the tube side of the heat exchanger and steam passes through on the shell side. In the heat exchanger, the liquid is heated to boiling, but boiling does not occur in the tubes because of the back pressure in the system. In the pilot plant, this back pressure is created by a designed gravity head assisted by **a** valve between the heat exchanger and the vapor body.

After passing through the heat exchanger, the liquid waste enters the vapor body, where boiling occurs, and vapor is released. The vapor consists of mostly water and volatile contaminants, both organic and inorganic. The liquid level in the vapor body is monitored through sight glasses located on the side of the vapor body vessel. The liquid level is controlled by the feed rate and brine purge rate. A portion of the concentrated brine is removed periodically from the vapor body in batches. When the brine temperature reaches a value corresponding to a specific brine boiling point resulting from a specific brine concentration, a valve at the bottom of the vapor body is opened and some of the brine is drained by gravity into a gallon waste brine drum. The vapor exits the vapor body to an entrainment separator, and the remaining heated process liquor is recirculated.

Depending on the nature of the feed waste, foaming may occur in the vapor body. If foaming is not controlled, foam can pass through the mesh pad of the evaporator, leave deposits in the catalytic oxidizer, plug the catalyst tray, and contaminate the product water. An antifoaming agent can be injected directly into the vapor body.

The vapor that exits the vapor body may contain mist droplets from the process liquor. The mist droplets from the boiling liquid waste could be carried through the process and deposit on the catalytic oxidizer, causing scaling, or contaminate the product condensate, if not removed. The entrainment separator is designed to remove these droplets from the vapor stream. The entrainment separator is periodically rinsed with water, and the rinse water is drained into the recirculation line of the system.

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2.3.3 Catalytic Oxidizer

The second step in the PO*WW*ER™ process is oxidation of volatile organics and inorganics in the vapor stream from the evaporator. The process is designed to operate with a catalyst in either a fluidized or static bed mode. The fluidized bed mode ensures sufficient contact between the catalyst and the vapor. However, because the pilot plant has been operated successfully in a static bed mode, this mode was used during the demonstration.

In a full-scale PO*WW*ER™ system, the oxidizer consists of three main pieces of equipment: the recuperative heat exchanger, the oxidizer heater, and the catalytic oxidizer. In a full-scale system, the inlet vapor is preheated along with oxidation air in a recuperative heat exchanger, with vapor exiting the catalytic oxidizer. The preheated vapor from the evaporator is further heated to oxidation temperature by the oxidizer heater, a direct-fired propane burner. Air is fed to the system by a blower. The heated vapor then enters the catalytic oxidizer and passes through the catalyst bed where oxidation takes place. The pressure drop across the catalyst bed is monitored at all times for clogs in the catalyst bed. Possible oxidation products include carbon dioxide (CO_2), water, hydrochloric acid (HCl), sulphur dioxide (SO_2), nitrogen oxides (NO_x), and products of incomplete combustion (PIC).

The PO*WW*ER™ pilot-scale plant at CWM's LCTC site differs from the full-scale system in two aspects: it does not have a recuperative heat exchanger and air is fed to the system by a compressor.

2.3.4 Scrubber

The third step of the PO*WW*ER™ technology involves scrubbing the vapor stream to neutralize the acid gases produced in the oxidizer. The scrubber consists of a packed bed in which the vapor passes countercurrently through caustic solution. The scrubber neutralizes and removes the acid gases produced by oxidation.

2.3.5 Condenser

Vapor exiting the scrubber is cooled and condensed in a shell-and-tube condenser. Vapor is cooled on the shell side by noncontact cooling water passing through the tube side. During the SITE demonstration, the temperature of

the product condensate was about 125 °F. The condenser is equipped with a vent to remove noncondensible gases. The product condensate is collected in a condensate holding tank, where it remains until it is transferred to a 250-gallon stainless steel product tank. This product liquid can either be reused as boiler or cooling tower makeup water, or discharged to surface water, if appropriate.

2.4 Innovative Features and Limitations of the PO*WW*ER™ Technology

The PO*WW*ER™ system combines two conventional technologies typically used in the chemical, petroleum, electronics, and hazardous waste industries, in a novel arrangement. Evaporation is a nonspecific separation process; all volatile material is vaporized depending on the relative volatility of each compound and the composition of the feed waste. The PO*WW*ER™ technology uses this lack of specificity advantageously to completely treat wastewaters.

The catalyst used in the PO*WW*ER™ system oxidizer is the main innovative feature of the system. The catalyst is a proprietary nonprecious metal oxide contained in a specific support medium. According to CWM, the catalyst is not as expensive or limited in versatility as a precious metal catalyst. The catalyst has been designed to withstand problems common to precious metal catalysts such as fouling, activity suppression, and poisoning. Due to the nature of the catalyst, periodic make-up is required to replace attrition losses.

The PO*WW*ER™ technology can treat concentrated and dilute aqueous wastes. Treatment of dilute aqueous wastes may require increased energy requirements, however, brine disposal costs will be significantly lower. In addition, the PO*WW*ER™ technology is advantageous for treating process wastewaters that produce recyclable brine. If brine cannot be recycled, it needs off-site treatment and disposal.

2.5 Key Contacts

Additional information on the PO*WW*ER™ technology and SITE program can be obtained from the following sources:

The PO*WW*ER™ Technology

<u>Technology Developer Representative</u>

Mr. Myron Reicher
Chemical Waste Management, Inc.
c/o AR1 Technologies, Inc.
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Schaumburg, IL 60173
(708) 706-6900

<u>Technology Licenser Representative</u>

Annamarie B. Connolly
ARI Technologies, Inc.
1501 E. Woodfield Road
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The SITE Program

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Section 3
Technology Applications Analysis

This section addresses the applicability of the PO*WW*ER™ system in treating aqueous wastes containing volatile organic compounds (VOC), semivolatile organic compounds (SVOC), cyanide, ammonia, and metals. CWM's claims regarding the applicability and performance of the PO*WW*ER™ system are included in Appendix A.

The applicability of the PO*WW*ER™ system was evaluated in terms of technical criteria used to select actions at Superfund sites. These criteria, which can also be applied to RCRA, underground storage tank (UST), and other corrective action decisions, include the following: (1) treatment effectiveness for volume reduction, (2) treatment effectiveness for toxicity reduction, (3) compliance with regulatory requirements, (4) implementability, (5) short-term impact, and (6) long-term effectiveness. These criteria are discussed in the following sections. Factors influencing the system's performance and reliability in meeting these criteria and evaluation limitations are discussed at the end of this section.

The discussion presented below is based on results of the PO*WW*ER™ system SITE demonstration at the LCTC site (see Appendix B) and several other case studies conducted by CWM for various private clients (see Appendix C). The technology demonstration was conducted under one set of operating parameters, which were established by CWM based on past operating experience with the PO*WW*ER™ system. These operating parameters were used in two sets of test runs: one set of three replicate test runs using unspiked LCTC landfill leachate and one set of three replicate test runs using LCTC landfill leachate spiked with VOCs, SVOCs, and metals. Each demonstration test run required about 9 hours of PO*WW*ER™ system operation in order to conduct sampling and monitoring. During the SITE demonstration, the evaluation of the PO*WW*ER™ system was restricted by testing limitations imposed by CWM. These limitations are discussed in Section 3.8.

The SITE demonstration and case study results indicate that the PO*WW*ER™ system can process a wide variety of wastewaters with different contaminant concentrations. According to CWM, the PO*WW*ER™ system can effectively treat the following: landfill leachate, contaminated well water, contaminated lagoon water, fuels decant water, oil emulsion wastewater, and wastewater contaminated with nitrogen-containing organic compounds and cyanide. CWM also states that the PO*WW*ER™ system can treat wastewater containing VOCs, SVOCs, pesticides, herbicides, solvents, heavy metals, cyanide, ammonia, nitrate, chloride, and sulfide.

Although an extensive data base has been generated on the PO*WW*ER™ system's effectiveness in treating various wastewaters, the technology's performance is best predicted by bench-scale testing. Certain contaminants may behave differently in association with other compounds and under different pH conditions. Therefore, preliminary testing is important in determining the technology's applicability to meet treatment objectives. Preliminary treatability studies may also help determine approximate process rates **and** feed waste adjustments required, allowing assessment of the PO*WW*ER™ system's site-specific applicability.

At the LCTC site, the SITE demonstration was conducted using a pilot-scale PO*WW*ER™ system. Therefore, observations made during the SITE demonstration should be used with critical engineering judgement when projecting full-scale PO*WW*ER™ system performance.

3.1 Treatment Effectiveness for Volume Reduction

The PO*WW*ER™ system reduces the volume of an aqueous waste by evaporation and concentrates nonvolatile contaminants in the brine. During each 9-hour test run, the PO*WW*ER™ system processed about 98 gallons of feed waste. Brine was wasted and sampled only once during the

9-hour test period. The total amount of brine wasted during each 9-hour test run was about 4.8 gallons, or about 5 percent of the total feed waste volume.

The PO*WW*ER™ system's effectiveness for volume reduction was evaluated based on the concentration ratio, which is defined as the ratio of total solids (TS) concentration in the brine over the TS concentration in the feed waste. The concentration ratio based on TS was estimated to be about 31 to 1 during the unspiked tests and 32 to 1 during the spiked tests. To confirm this estimate, the concentration ratio was also estimated based on the ratio of chloride and metals in the brine and feed waste. The chloride concentration ratio was 33 to 1 during the unspiked tests and 3 1 to 1 during the spiked tests. The metals concentration ratio was 33 to 1 during the unspiked tests and 30 to 1 during the spiked tests.

Results from other case studies (see Appendix C) show that the PO*WW*ER™ system achieved TS concentration ratios ranging from 35 to 1 to 50 to 1. Brine TS concentrations ranged from 28 to 80 percent.

3.2 Treatment Effectiveness for Toxicity Reduction

The PO*WW*ER™ system's effectiveness for toxicity reduction was evaluated based on the following criteria: (1) VOC removal, (2) SVOC removal, (3) ammoniaandcyanide removal, (4) noncondensible gas emissions, and (6) acute toxicity. These criteria are discussed below.

3.2.1 VOC Removal

The PO*WW*ER™ system effectively removes VOCs from the feed waste during evaporation. The VOCs are subsequently oxidized in the catalytic oxidizer. The product condensate contains nondetectable amounts of VOCs. During the SITE demonstration, VOC oxidation efficiencies were not determined (see Section 3.8 for details).

Acetone, 2-butanone, methylene chloride, tetrachloroethene (PCE), toluene, and vinyl chloride were identified as critical VOCs for the PO*WW*ER™ system SITE demonstration. However, vinyl chloride was not detected in any samples analyzed and therefore is not discussed further. During the spiked tests, feed waste was spiked with the following VOCs, each at levels of 100 milligrams per liter (mg/L): methylene chloride, PCE, and toluene. The purpose of spiking the feed waste was to test the effect of contaminant loading on VOC treatment efficiency.

During the unspiked test runs, the acetone concentration in feed waste samples ranged from 8,200 to 12,000 micrograms per liter (μg/L); in brine samples it was less than the detection limit of 100 ug/L during the first and second unspiked test runs and 140 μg/L during the third unspiked test run; and in product condensate samples it was less than the detection limit of 10 ug/L. During the spiked test runs, the acetone concentration in feed waste samples ranged from 13,000 to 18,000 ug/L; in brine samples it ranged from 180 to 220 ug/L. The results indicate that during the spiked test runs, acetone was not completely removed from the brine. Because acetone was not one of the spiking compounds, the results suggest that total contaminant loading, which increased during spiking, had a measurable effect on the acetone evaporation efficiency. However, the concentration of acetone in product condensate samples during the spiked test runs was less than the detection limit of 10 μg/L, indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, the 2-butanone concentration in feed waste samples ranged from 1,500 to 2,200 μg/L; in brine samples it was less than the detection limit of 100 ug/L; and in product condensate samples it was less than the detection limit of 10 μg/L. During the spiked test runs, the 2-butanone concentration in feed waste samples was less than the detection limit of 10,000 μg/L; in brine samples it was less than the detection limit of 100 μg/L; and in product condensate samples it was less than the detection limit of 10 ug/L. These results indicate that total contaminant loading had no measurable effect on the 2-butanone evaporation efficiency or product condensate quality.

During the unspiked test runs, the methylene chloride concentration in feed waste samples ranged from 640 to 1,700 ug/L; in brine samples it was less than the detection limit of 50 ug/L; in product condensate samples it was less than the detection limit of 5 μg/L during the first and third unspiked test runs. However, during the second unspiked test run, the concentration of methylene chloride in product condensate ranged from 5 to 8 μg/L. During the spiked test runs, methylene chloride concentrations in feed waste samples ranged from 88,000 to 110,000 μg/L; in brine samples it ranged from 110 to 200 μg/L. The results suggest that total contaminant loading, which increased during the spiked test runs, had a slight but measurable effect on methylene chloride evaporation efficiency. However, the concentration of methylene chloride in product condensate samples was less than the detection limit of 5 μg/L,

indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, the PCE concentration in feed waste samples was less than the detection limit of 500 µg/L; in brine samples it was below the detection limit of 50 µg/L; in product condensate samples it was less than the detection limit of 5 µg/L. During the spiked test runs, the PCE concentration in feed waste samples ranged from 47,000 to 60,000 µg/L; in brine samples it ranged from less than the detection limit of 50 to 69 µg/L. The results suggest that total contaminant loading, which increased during the spiked test runs, had a slight but measurable effect on PCE evaporation efficiency. However, the concentration of PCE in product condensate samples was less than the detection limit of 5 µg/L, indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, the toluene concentration in feed waste samples was less than the detection limit of 500 µg/L; in brine samples it was less than the detection limit of 50 µg/L; and in product condensate samples it was less than the detection limit of 5 µg/L. During the spiked test runs, the toluene concentration in feed waste samples ranged from 46,000 to 69,000 µg/L; in brine samples it was less than the detection limit of 50 µg/L; and in the product condensate, it was less than the detection limit of 5 µg/L. The results suggest that total contaminant loading had no measurable effect on the toluene evaporation efficiency or on product condensate quality.

During other case studies conducted by CWM (see Appendix C), landfill leachate spiked with 100 mg/L of each of the following VOCs was treated in the PO*WW*ER™ pilot plant: acetone, carbon disulfide, chlorobenzene, methanol, methyl ethyl ketone, methylene chloride, toluene, and trichloroethene. The results show that all of the spiking VOCs were effectively evaporated from the brine and successfully oxidized in the catalytic oxidizer. Oxidation efficiencies greater than 99 percent were achieved.

In another case study conducted by CWM, landfill leachate spiked with methanol ranging from 500 to 5,000 mg/L was treated in the PO*WW*ER™ pilot plant. Methanol was effectively evaporated and oxidized. An overall removal efficiency of 98 percent was achieved.

3.2.2 SVOC Removal

The PO*WW*ER™ system removes some SVOCs from the feed waste during evaporation. The evaporated SVOCs are subsequently oxidized in the catalytic oxidizer. SVOCs with relatively high boiling points do not totally vaporize but remain in the brine. The product condensate contains nondetectable amounts of SVOCs. During the SITE demonstration, SVOC oxidation efficiencies were not determined (see Section 3.8 for details).

Benzoic acid and phenol were identified as critical SVOCs for the PO*WW*ER™ system SITE demonstration. During the spiked tests, feed waste was spiked with 10 mg/L of phenol to test the effect of contaminant loading on SVOC treatment efficiency.

During the unspiked test runs, the benzoic acid concentration in feed waste samples ranged from 6,300 to 24,000 µg/L; in brine samples it ranged from 600,000 to 1,600,000 µg/L; and in product condensate samples it was less than the detection limit, which ranged from 25 to 130 µg/L. During the spiked test runs, the benzoic acid concentration in feed waste samples ranged from 13,000 to 24,000 µg/L; in brine samples concentrations ranged from 620,000 to 930,000 µg/L; and in product condensate samples it was less than the detection limit, which was 130 µg/L for most samples analyzed. The results indicate that during the unspiked and spiked test runs, benzoic acid concentrated primarily in the brine.

During the unspiked test runs, the phenol concentration in feed waste samples ranged from 5,300 to 11,000 µg/L; in brine samples it was less than the detection limit of 200,000 µg/L; and in product condensate samples it was less than the detection limit, which ranged from 10 to 50 µg/L. During the spiked test runs, the phenol concentration in feed waste samples ranged from 12,000 to 17,000 µg/L; in brine samples it was less than the detection limit of 200,000 µg/L; and in product condensate samples it was less than the detection limit of 50 µg/L. The results indicate that phenol apparently vaporizes, at least partially, and is presumably oxidized in the catalytic oxidizer.

Although benzoic acid and phenol are both acidic compounds, they have very different physical-chemical properties. Given these properties, phenol is more likely than benzoic acid to be removed from the brine. Phenol has a vapor pressure over 30 times greater than that of benzoic

acid. Also, under the test conditions, phenol was likely present in the brine primarily in unionized form while benzoic acid was likely present in ionized form.

Results from other case studies also indicate that certain SVOCs vaporize and are successfully oxidized (see Appendix C). However, SVOCs with high boiling points will generally concentrate in the brine.

3.2.3 Ammonia and Cyanide Removal

Ammonia and cyanide evaporation efficiency in the PO*WW*ER™ system depends on the feed waste pH and the types of metals present. Under certain conditions, the PO*WW*ER™ system vaporizes ammonia and cyanide in the evaporator and effectively oxidizes both in the catalytic oxidizer. During the SITE demonstration, ammonia and cyanide oxidation efficiencies were not determined (see Section 3.8 for details). Ammonia forms very strong complexes with cadmium, cobalt, copper, silver, mercury, nickel, and zinc. Cyanide forms complexes with cadmium, copper, silver, mercury, iron, nickel, and zinc. All the above-mentioned metals were present in feed waste samples taken during unspiked and spiked test runs. The metal complexes of ammonia and cyanide need to be destroyed before cyanide can be evaporated and oxidized. Free ammonia volatilizes effectively at pH values greater than 9, while free cyanide volatilizes effectively at pH values less than 9.

During the unspiked test runs, the ammonia concentration in feed waste samples ranged from 150 to 160 mg/L; in brine samples it ranged from 5.4 to 23 mg/L; and in product condensate samples it was less than the detection limit of 0.1 mg/L. During the spiked test runs, the ammonia concentration in feed waste samples ranged from 140 to 160 mg/L; in brine samples it ranged from 7.4 to 7.8 mg/L. The results indicate that during the unspiked and spiked test runs, ammonia was not completely removed from the brine, possibly because the feed waste pH ranged from 8.5 to 9.1, close to the lower optimum pH range for ammonia volatilization, or because ammonia complexed with metals, which were present in the feed waste. The concentration of ammonia in product condensate was less than the detection limit of 0.1 **mg/L for** all samples analyzed, indicating that total contaminant loading, which increased during the spiked test runs, had no measurable effect on product condensate quality.

During the unspiked test runs, the cyanide concentration in feed waste samples ranged from 25 to 34 mg/L; in brine

samples it ranged from 77 to 150 mg/L; and in product condensate samples it was less than the detection limit of 0.01 mg/L. During the spiked test runs, the cyanide concentration in feed waste samples ranged from 24 to 36 mg/L; in brine samples it ranged from 17 to 77 mg/L. The results indicate that during the unspiked and spiked test runs, cyanide was not completely removed from the brine, possibly because the feed waste pH ranged from 8.5 to 9.1, which is close to the upper optimum pH range for cyanide volatilization, or because cyanide complexed with metals, which were present in the feed waste. The concentration of cyanide in product condensate was less than the detection limit of 0.01 mg/L for all samples analyzed, indicating that total contaminant loading had no measurable effect on product condensate quality.

During one case study conducted by **CWM,** wastewater contaminated with nitrogen-containing organic compounds and cyanide was treated in the PO*WW*ER™ pilot plant (see Appendix C). The pH of the feed waste ranged from 4 to 4.42. Cyanide removal efficiencies ranging from 96.9 to 99.99 percent were achieved. Cyanide oxidation efficiencies ranged from 93.5 to 99.96 percent. Ammonia removal efficiencies ranging from 91.6 to greater than 99.6 percent were achieved. Ammonia oxidation efficiencies ranged from 83.8 to greater than 99.6 percent.

In another case study conducted by CWM, well water spiked with cyanide at 139 mg/L was treated (see Appendix C). The well water was acidified to cause the release of hydrogen cyanide (HCN) gas. Cyanide was removed from the brine to below the detection limit. Cyanide in the product condensate also was below the detection limit.

Results from another case study conducted by CWM (see Appendix C) with landfill leachate spiked with ammonia ranging from 75 to 2,880 mg/L indicate that ammonia was effectively evaporated when the feed waste pH ranged from 9 to 11.

In another case study, landfill leachate spiked with 1,000 mg/L ammonia was treated in the PO*WW*ER™ system (see Appendix C). At pH 11, ammonia evaporation efficiency was significantly higher than at a pH ranging from 7 to 8.

3.2.4 Noncondensible Gas Emissions

During the SITE demonstration, continuous emissions monitoring (CEM) of the noncondensible vent gas was

conducted. CO, SO2, and NOx are critical analytes and are discussed below. The average CO concentrations ranged from 9.58 to 37.3 parts per million by volume (ppmv), resulting in emissions ranging from $1.1x10^{-3}$ to $3.92x10^{-3}$ pounds per hour(lb/hr). The 60minute maximum CO concentrations ranged from 11.1 to 40.8 ppmv, resulting in emissions ranging from $1.27x10^{-3}$ to $4.28x10^{-3}$ lb/hr. The average SO2 concentrations were less than 2 ppmv, resulting in emissions of less than $5.5x10^{-4}$ lb/hr. The 60 minute maximum SO2 concentrations ranged from less than 2 to 3.49 ppmv, resulting in emissions ranging from less than $5.5x10^{-4}$ to $8.4x10^{-4}$ lb/hr. The average NOx concentrations ranged from 233 to 292 ppmv, resulting in emissions ranging from $3.46x10^{-2}$ to $5.03x10^{-2}$ lb/hr. The 60-minute maximum NOx concentrations ranged from 241 to 309 ppmv, resulting in emissions ranging from $3.59x10^{-2}$ to $5.34x 10^{-2}$ lb/hr. The noncondensible vent gas emissions for these parameters met the proposed regulatory requirements for the LCTC site.

During the SITE demonstration, noncondensible vent gas samples were collected and analyzed for VOCs, SVOCs, and HCl. The following VOCs were detected at trace levels: chloromethane; bromomethane; methylene chloride; acetone; carbon disulfide; 2-butanone; 1,1, 1-trichloroethane; benzene; PCE; toluene; chlorobenzene; and ethylbenzene. Acetone, 2-butanone, methylene chloride, PCE, and toluene are critical analytes consistently present in the feed waste. The critical VOC present in the noncondensible vent gas at the highest concentration was PCE. During the first and third unspiked test runs, the concentration of PCE was less than the detection limits of 2.47 and 2.44 ppmv, respectively. During the second unspiked run, PCE was present at 3.93 ppmv. During the spiked test runs, the concentration of PCE ranged from 173 to 285 ppmv. The highest PCE concentration occurred during the first spiked test run, which also had the highest NOx, SO2, CO, and total nonmethane hydrocarbon (TNMHC) concentrations. All other VOCs were present at concentrations less than 50 micrograms per dry standard cubic meter (μg/dscm) and usually below 10 ug/dscm.

HCl and some SVOCs were also detected in noncondensible vent gas samples. HCl was detected only during the second and third unspiked test runs at concentrations of 48.6 and 247 ug/dscm, respectively.

The following SVOCs were also present in the noncondensible gas emissions at trace levels: phenol, benzoic acid, bis-(Zethylhexyl) phthalate, and di-n-octylphthalate. During the unspiked test runs, SVOCs were present at the following concentrations: phenol from less than 1.4 to 1.6 ug/dscm, benzoic acid from less than 6.8 to 6.8 ug/dscm, bis-(Zethylhexyl) phthalate at less than 1.4 μg/dscm, and di-n-octylphthalate from less than 1.4 to 3.9 ug/dscm. During the spiked test runs, phenol concentrations ranged from less than 1.4 to 1.7 μg/dscm, benzoic acid concentrations ranged from less than 6.7 to 3 1.8 ug/dscm, bis-(2-ethylhexyl) phthalate concentrations ranged from less than 1.3 to 31.4 ug/dscm, and di-n-octylphthalate concentrations ranged from less than 1.4 to 9 μg/dscm.

During the SITE demonstration, TNMHC concentration was monitored by the CEM system. During the unspiked test runs, the average and maximum TNMHC was less than the detection limit of 2 ppmv, resulting in emissions of less than $3.7x10^{-4}$ lb/hr. During the spiked test runs, the average TNMHC was also less than the detection limit of 2 ppmv, resulting in emissions of less than $3.7x 10^{-4}$ lb/hr. However, during the spiked test runs, the maximum TNMHC concentration ranged from 2.53 to 3.59 ppmv, resulting in emissions ranging from $3.8x10^{-4}$ to $6.7x10^{-4}$ lb/hr.

Noncondensible gas emissions results from the SITE demonstration indicate that increases in total contaminant loading result in slight increases in contaminant concentrations in the vent gas. However, the noncondensible vent gas emissions met the proposed regulatory requirements for the LCTC site.

3.2.5 Acute Toxicity

The ability of the PO*WW*ER™ technology to produce nontoxic product condensate was evaluated by collecting grab samples of leachate feed and product condensate and testing those samples for acute toxicity. The tests were performed off site with the freshwater species Ceriodaphnia dubia (a cladocera) and Pimephales promelas (fathead minnow), and the marine species Mysidopsis bahia (mysid shrimp) and Cyprinodon variegatus (sheepshead minnow). Acute toxicity was measured by counting the number of organisms surviving after 48 hours of exposure to leachate feed, product condensate, and control water. The survival data were used to compute a median lethal concentration (LC50). The LC50 represents a sample concentration, which is expressed as a percentage that is lethal to 50 percent of the test organisms.

Acute toxicity was measured using two sample conditions. Condition 1 involved adjusting feed

and product condensate to equivalent pH, temperature, and hardness or salinity levels to meet demonstration objectives, and as allowed in EPA acute toxicity testing procedures. The adjusted levels were optimal for survival of the test species (EPA, 1991) and sources of toxicity other than metals and organics were absent. Condition 2 involved adjusting product condensate pH and temperature to the same levels used in Condition 1, but without hardness adjustment. Salinity was not adjusted for Condition 2 because only freshwater species were tested.

Acute toxicity results show that the PO*WW*ER™ technology reduced sources of acute toxicity in leachate feed. Condition 1 leachate feed samples were highly toxic, with LC50 values consistently less than 10 percent, while product condensate samples were consistently nontoxic, with no statistically significant difference in acute toxicity between 100 percent product condensate and the control (LC50 was less than 100 percent). Ceriodaphnia dubia was the most sensitive of the four species to leachate feed.

Sample conditions such as pH, temperature, and hardness can influence the toxicity test (EPA, 1991). Field measurements taken during the SITE demonstration at the LCTC site show that product condensate discharged from the PO*WW*ER™ technology had an average temperature of about 125 °F and a pH of between 3.83 and 4.27. Acute toxicity may occur in unacclimated species from elevated temperatures and low pH. Also, the PO*WW*ER™ technology produces **a** product condensate with a hardness, as measured in the laboratory, of less than 1 mg/L as calcium carbonate. This lack of hardness increased acute toxicity. Condition 2 results indicate that product condensate without hardness adjustment was acutely toxic to both freshwater species.

3.3 Compliance With Regulatory Requirements

This subsection discusses specific environmental regulations pertinent to the operation of the PO*WW*ER™ technology, including the transport, treatment, storage, and disposal of wastes generated during the operation of the PO*WW*ER™ system. The regulations that apply to a particular remediation activity depend on the type of remediation site and the type of waste being treated. These regulations include the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); RCRA; the Clean Water Act (CWA); the Safe Drinking Water Act (SDWA); the Clean Air Act (CAA); the Toxic Substances Control Act (TSCA); various radioactive waste

regulations; mixed waste regulations; and the Occupational Safety and Health Act (OSHA).

3.3.1 CERCLA

CERCLA, as amended by SARA of 1986, provides for federal authority to respond to releases of hazardous substances, pollutants, or contaminants to air, water, and land (Federal Register, 1990a). Section 121 (Cleanup Standards) of SARA requires that selected remedies be protective of human health and the environment and be cost-effective. SARA states a preference for remedies that are highly reliable, provide long-term protection, and employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants. Section 121 also requires that remedies selected at Super-fund sites comply with federal and state applicable or relevant and appropriate requirements (ARAR). Six conditions exist under which ARARs for a remedial action may be waived: (1) the action is an interim measure and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to human health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state standard has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated (EPA, 1988).

Generally, contaminated water and noncondensible gas emissions treatment using the PO*WW*ER™ technology will take place on site, but treated water (product condensate) reuse or discharge and brine disposal may take place either on site or off site. On- and off-site actions must meet the substantive requirements (for example, emission standards) of all ARARs. Off-site actions must also meet permitting and any other administrative requirements of environmental regulations.

3.3.2 RCRA

RCRA, as amended by the Hazardous and Solid Waste Amendments of 1984, regulates management and disposal of municipal and industrial solid waste. The EPA and RCRA-authorized states (listed in 40 Code of Federal Regulations [CFR] Part 272) implement and enforce RCRA and RCRA-equivalent state regulations.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261, Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261, Subpart D.

The **PO*WW*ER**™ technology has been used to treat industrial wastewaters and landfill leachate contaminated with a variety of organic and inorganic contaminants. Contaminated water to be treated by the **PO*WW*ER**™ technology will probably be hazardous or sufficiently similar to hazardous waste so that RCRA requirements will apply. If contaminated water to be treated is determined to be a hazardous waste, the **PO*WW*ER**™ technology will need to meet 40 CFR Part 265 standards for tank storage (Subpart J) because the technology includes tank storage of contaminated and treated water. Also, RCRA treatment requirements must be met.

Brine and product condensate generated during treatment must be stored and disposed of properly. If contaminated water treated by the **PO*WW*ER**™ technology is a listed waste, treatment residues (brine and product condensate) will be considered listed wastes unless RCRA delisting requirements are met. If treatment residues are not listed wastes, they should be tested to determine if they are RCRA characteristic hazardous wastes. The brine should also be tested using EPA Method 9095 (paint filter liquids test) to determine if it contains free liquids. During the SITE demonstration brine contained free liquids. However, brine characteristics may vary for different applications depending on feed waste characteristics. Wastes containing no free liquids are excluded from various leak detection and secondary containment requirements for disposal. If the brine is not hazardous and does not contain free liquids, it can be disposed of at a nonhazardous waste landfill. If the brine or product condensate is hazardous, the RCRA standards discussed below apply.

In 40 CFR Part 262, standards for generators of hazardous waste are presented. These requirements include obtaining an EPA identification number, meeting waste accumulation standards, labeling wastes, and maintaining appropriate records. Part 262 allows generators to store wastes up to 90 days without a permit and without having interim status as a treatment, storage, or disposal facility. If

treatment residues are stored on site for 90 days or more, 40 CFR Part 265 requirements apply.

Any facility designated for permanent disposal of hazardous wastes must be in compliance with RCRA. Disposal facilities must fulfill permitting, storage, maintenance, and closure requirements presented in 40 CFR Parts 264 through 270. In addition, any authorized state RCRA requirements must be fulfilled. If treatment residues are disposed of off site, 40 CFR Part 263 transportation standards apply.

For both CERCLA actions and RCRA corrective actions, the brine waste generated by the **PO*WW*ER**™ technology will be subject to federal Land Disposal Restrictions (LDR) if it is hazardous and land disposed (EPA, 1989a). Several LDR compliance alternatives exist for disposing of brine waste if it is hazardous: (1) comply with the LDR in effect; (2) comply with the LDRs by choosing one of the LDR compliance alternatives (for example, treatability variance, no migration petition); or (3) invoke an ARAR waiver (this option applies only to on-site CERCLA disposal).

In 40 CFR Part 264, Subparts F (promulgated) and S (proposed), requirements for corrective action at RCRA-regulated facilities are presented. These subparts generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, remediating ground water, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites (Federal Register, 1990b).

During the SITE demonstration, the **PO*WW*ER**™ system at the LCTC site treated a listed hazardous waste-F039, landfill leachate. Therefore, the product condensate and waste brine were also considered hazardous wastes. However, if the leachate was not a listed waste, the product condensate and brine would need to be tested for hazardous waste characteristics.

Based on the SITE demonstration test results, the product condensate contained no detectable levels of VOCs and SVOCs and only trace levels of metals. If the product condensate was not a listed waste, it could have been disposed of as nonhazardous waste. The brine, however, exhibited the hazardous characteristic of toxicity and has

the potential to exhibit the characteristic of reactivity because of its cyanide content (see Section 3.6.2). Hazardous contaminants in the feed waste that do not evaporate or oxidize in the PO*WW*ER™ system concentrate in the brine; therefore, this treatment residual will likely always be a hazardous waste.

3.3.3 CWA

The National Pollutant Discharge Elimination System (NPDES) permitting program established under the CWA issues, monitors, and enforces permits for direct discharges to surface water bodies. Discharges to off-site receiving waters or to publicly owned treatment works (POTW) must comply with applicable federal, state, and local administrative and substantive requirements. Effluent limits are specified in the NPDES permit issued for direct discharges to off-site receiving waters. NPDES permits protect aquatic life by imposing chemical-specific limits and whole effluent toxicity (WET) limits. WET is defined in 40 CFR Part 122.2. EPA-approved test methods for measuring acute and chronic WET are referenced in 40 CFR Part 136. **No NPDES** permits are required for on- or off-site discharges to POTWs, but all substantive requirements (such as discharge limitations) should be identified and achieved. Discharges to POTWs are generally regulated through local sewer use ordinances.

Based on the SITE demonstration test results, the product condensate could probably be discharged to either a POTW without further treatment or to a nearby surface water body after additional treatment. Additional treatment would probably include increasing the pH from about 4, increasing the hardness from less than 1 mg/L, and decreasing the temperature from about 125 °F. Final pH, hardness, and temperature levels are site-specific and will need to be determined for each discharge location.

3.3.4 SDWA

The SDWA as amended in 1986 includes the following programs: (1) drinking water standards; (2) underground injection control (UIC); and (3) sole-source aquifer and well-head protection.

SDWA drinking water primary (health-based) and secondary (aesthetic) maximum contaminant levels (MCLs) are generally appropriate cleanup standards for water that is or may be used as a source of drinking water. In some cases, alternate concentration limits (ACL) are appropriate (for example, in cases where multiple contaminants are present). Decision makers should refer to CERCLA and RCRA standards for guidance in establishing ACLs. The SITE demonstration test results show that the product condensate has the potential to meet MCLs and ACLs.

Water discharge through injection wells is regulated under the UIC program. This program categorizes injection wells as Classes I through V, depending on their construction and use. Reinjection of treated water (product condensate) involves Class IV (reinjection) or Class V (recharge) wells and should meet the appropriate requirements for well construction, operation, and closure.

The sole-source aquifer protection and well-head protection programs aredesigned to protect specific drinking water supply sources. If such a source is to be remediated, appropriate regulatory agency officials should be notified, and any potential problems should be identified before treatment begins.

3.3.5 CAA

Pursuant to the CAA, EPA has set national ambient air quality and pollutant emissions standards. CAA requirements generally apply to the PO*WW*ER™ technology noncondensible gas emissions. Noncondensible gas emissions should be monitored to ensure that they comply with CAA standards, especially for CO and NO_x. During the SITE demonstration, the noncondensible gas emissions met proposed permit levels for CO, NO_x, and SO_2 at the LCTC site. The respective average and maximum permitted discharge rates for CO, NO_x, and SO_2 are 0.15 and 1.5; 0.25 and 2.5, and 0.25 and 2.5 lb/hr.

RCRA air standards generally must be met for CERCLA response actions and RCRA corrective actions. Forthcoming RCRA regulations (40 CFR Part 269) will address air emissions from hazardous waste treatment, storage, or disposal facilities. When promulgated, these requirements will include air emission standards for equipment leaks and process vents. These requirements will cover any fugitive air emissions from the PO*WW*ER™ technology. Also, states' programs to regulate toxic air pollutants, when established, will be the most significant regulations affecting environmental remediation activities.

3.3.6 TSCA

Testing, **premanufacture** notification, and recordkeeping requirements for toxic substances are regulated under TSCA. TSCA also includes storage requirements for polychlorinated biphenyl (PCB) (see 40 CFR Part 761.65).

Because the **PO*WW*ER™** technology has the potential to handle wastewaters or leachates containing PCBs, PCB storage, treatment, and disposal requirements will apply if PCB-contaminated wastes are treated. The EPA document entitled "CERCLA Compliance with Other Laws Manual, Part II: Clean Air Act and Other Environmental Statutes and State Requirements"discusses TSCA as it pertains to Super-fund actions (EPA, 1989b). For ground-water remediation at Super-fund sites and RCRA corrective action sites, the treatment standard is generally the SDWA MCL of 0.05 µg/L for PCBs. RCRA LDRs for PCBs may also apply, depending on the liquid waste PCB concentration (see 40 CFR Part 268).

3.3.7 Radioactive Waste Regulations

The **PO*WW*ER™** technology has the ability to treat water contaminated with radioactive materials. Decisions concerning appropriate requirements for sites contaminated with radioactive waste should be based on the following factors: (1) type of radioactive constituents present and how they contaminate the site; (2) regulatory agency the site is subject to; and (3) most protective or appropriate regulations. The primary agencies that regulate the cleanup of radioactively contaminated sites are EPA, the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the states. In addition, nongovernmental agencies may issue advisories or guidance, which should also be considered in developing a protective remedy.

The SDWA has established MCLs for radionuclides in community water as a concentration limit for alpha-emitting radionuclides and as an annual dose limit for the ingestion of beta and gamma-emitting radionuclides. These standards are appropriate in setting cleanup standards for radioactively contaminated water. Discharge of treated water (product condensate) from radioactively contaminated sites could be subject to 40 CFR Part 440, Subpart C, which establishes radionuclide concentration limits for liquid effluent from facilities that extract and process uranium, radium, and vanadium ores. The **PO*WW*ER™** technology has the potential to treat water to well within radioactivity limits established by these regulations. However, treated water should be tested to ensure that such limits are met.

Any fugitive radioactive air emissions resulting from the **PO*WW*ER™** technology must comply with radionuclide emissions standards promulgated under the CAA (codified in 40 CFR Part 61).

The Environmental Radiation Protection Standards (40 CFR Part 190) promulgated under the authority of the Atomic Energy Act (AEA) set standards for radiation doses to the general public caused by normal operations within the uranium fuel cycle. These requirements should be considered at sites where uranium fuel waste is being treated or disposed of. Standards regulating the stabilization, control, and disposal of uranium and thorium mill tailings are included in 40 CFR Part 192. These regulations set cleanup, control, and release standards for radioactive materials.

NRC regulations cover the possession and use of source, by-product, and special nuclear materials by NRC licensees. These regulations apply to sites where radioactive contamination exists. Ten CFR Parts 20, 30, 40, 61, and 70 cover protection of workers and the public from radiation, discharges of radionuclides to air and water, and waste treatment and disposal requirements for radioactive waste. The brine and product condensate generated by the **PO*WW*ER™** technology during treatment of radioactive water may be regulated under these regulations if they contain residual radioactivity.

DOE requirements are included in a series of internal DOE orders that have the same force as regulations at DOE facilities. These DOE directives should be considered when developing protective remedies at CERCLA sites or RCRA corrective action sites, although they apply directly only to DOE sites. DOE orders address exposure limits for the public, concentrations of residual radioactivity in soil and water, and management of radioactive wastes (DOE, 1988).

3.3.8 Mixed Waste Regulations

Use of the **PO*WW*ER™** technology at sites with radioactive contamination may involve the treatment or generation of mixed waste. Mixed waste contains both radioactive and hazardous components as defined by AEA and RCRA and is subject to the requirements of both acts. When the application of both regulations results in a situation inconsistent with the AEA (for example, an increased likelihood of radioactive exposure), AEA requirements supersede RCRA requirements.

EPA's Office of Solid Waste and Emergency Response (OSWER), in conjunction with the NRC, issued several directives to assist in the identification, treatment, and disposal of low-level radioactive mixed waste. Various OSWER directives include guidance on defining,

identifying, and disposing of commercial mixed low-level radioactive and hazardous wastes (EPA, 1987). If the PO*WW*ER™ technology is used to treat low-level mixed wastes, these directives should be considered. If high-level mixed waste or transuranic mixed waste is treated, DOE internal orders should be considered when developing a protective remedy (DOE, 1988).

3.3.9 OSHA

CERCLA response actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 29 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA (Safety and Health Regulations **for** Construction). For example, construction of electric utility hookups for the PO*WW*ER™ technology will need to comply with Part 1926, Subpart K (Electrical). Product chemicals, such as sodium hydroxide, that will likely be used for pre- or post-treatment with the PO*WW*ER™ technology will need to comply with Part 1926, Subparts D (Occupational Health and Environmental Controls) and H (Materials Handling, Storage, and Disposal). Also, state requirements that are more stringent than OSHA requirements will need to be met.

3.4 PO*WW*ER™ System Implementation

PO*WW*ER™ system implementation includes site preparation, operation and maintenance (O&M), reliability, and personnel requirements. These aspects of implementation are discussed below. Because PO*WW*ER™ system is to be marketed on a turnkey basis, the system will be set up by the technology licenser, AR1 Technologies, Inc. (ARI). The owner is required to provide utilities.

CWM, the technology developer, has built two pilot- and one full-scale PO*WW*ER™ plants. One PO*WW*ER™ pilot plant, with a processing capacity of 0.5 gallon per minute (gpm), was built in February 1988 at the LCTC site in Lake Charles, Louisiana. The plant has been used for demonstration purposes. The SITE demonstration was conducted at the LCTC site pilot plant. Another PO*WW*ER™ pilot plant with a processing capacity of 1.5 gallons per hour (gph) was built in December 1991 in Clemson, South Carolina. This PO*WW*ER™ pilot plant has also been used for demonstration purposes. A full-scale PO*WW*ER™ plant was built at Yising Yi

Island in Hong Kong. This full-scale plant has a processing capacity of 50 gpm and started operating in December 1992.

According to CWM, the PO* WW*ER™-based system can be supplied as a single unit with modular construction for a processing capacity of up to 50 gpm for each module. Larger plants can either be supplied as multiple modular units, each with a processing capacity of up to 50 gpm, or designed for a given capacity as a single, integrated plant to be field fabricated and installed.

3.4.1 **Site *Preparation***

The 50-gpm PO*WW*ER™ system occupies approximately 4,000 square feet. Full-scale PO*WW*ER™ treatment systems will be designed to meet site-specific waste volume requirements and will therefore vary in size. Area requirements are not directly proportional to the PO* WW*ER™ system capacity. Equipment configuration is flexible, but adequate height allowances must be considered for the evaporator, which is about 50 feet tall. The PO*WW*ER™ system equipment should be placed on a level concrete pad, and equipment containing liquids should be located within a secondary containment.

At the LCTC site, the 0.5-gpm PO*WW*ER™ pilot plant was set up in a **concrete** bermed area. A trailer near the PO*WW*ER™ system was used as a command center with office space and computer access.

Site access requirements for the PO*WW*ER™ equipment are minimal. The site must be accessible to trailer trucks delivering PO*WW*ER™ equipment and any other vehicles needed to prepare the site. Site access can be restricted by a fence.

3.4.2 *Operation and Maintenance Requirements*

O&M requirements for the PO*WW*ER™ unit include general utility services and services and supplies. These requirements are discussed below.

Utilities

Operation of the PO*WW*ER™ system requires the following utilities:

- Electrical Power-The 50-gpm PO*WW*ER™ system requires a 440-volt, three-phase electrical service and uses 445 kilowatt hours (kWh). Additional 220-volt service is required for control room.

- Fuel-The 50-gpm PO*WW*ER™ system also requires approximately 22,000 standard cubic feet per hour (scfh) of natural gas for the burner that heats the catalytic oxidizer. Propane can also be used as an alternate fuel.

- Process Water-Water is needed for boiler and cooling tower make-up. Water can be supplied by an existing on-site water distribution system. If suitable, product condensate can be used for make-up water, Also, an air-cooled condenser can be used instead of a water-cooled system.

Utilities required for the PO*WW*ER™ technology demonstration are in place and operational at the LCTC site. If electricity and water are not readily available, provisions for obtaining a generator should be made to provide electricity and generate steam, and a tank for water storage. Outdoor lighting for 24-hour operation of the plant is available at the LCTC site and is required for other sites. The control room requires electricity for lighting and computer operation.

Services and Supplies

A number of readily obtainable services and supplies are required to operate the PO*WW*ER™ system. Major services needed for remedial activities may include (1) a ground-water or leachate collection or storage system, and (2) laboratory analyses and CEM to monitor the system's performance. The PO*WW*ER™ system requires a wastewater feed system.

Supplies required for operation of the PO*WW*ER™ system at Superfund and RCRA corrective action sites include (1) several consumable materials, (2) steel drums for waste brine disposal (waste brine may be collected directly into a tanker truck instead of steel drums), and (3) sample containers. Most of these services and supplies were already available at the LCTC site during the SITE demonstration. Consumable materials include antifoaming agent, sodium hydroxide or sulfuric acid for pH adjustment, and oxidizer catalyst.

Support facilities needed for the PO*WW*ER™ system demonstration include an office trailer, sanitary facilities, and temporary enclosures, such as tents, to cover monitoring equipment. Telephone service is also required to contact emergency services and to provide normal communications.

3.4.3 Reliability

Generally, the PO*WW*ER™ systemoperatedreliably during the SITE demonstration. During startup, the PO*WW*ER™ system at the LCTC site required about 9 days to reach steady-state operation because the solids content in the feed waste was lower than expected. After startup, a few minor operational problems were observed. This section summarizes operational observations made during the SITE demonstration at the LCTC site.

During the SITE demonstration, a l-hour area wide electrical power outage caused the temperature in the evaporator to drop, which resulted in the system deviating from steady-state conditions. The unit required 5 hours of continuous operation to return to steady state operation. Also, the evaporator recirculation pump shaft had to be manually turned to prevent the brine from solidifying in the lines.

Clogged sample lines limited sampling of the brine until a new sampling location was made available during the PO*WW*ER™ system demonstration. Brine sample lines were easily clogged because of their small internal diameter (0.25 inch) and minimal line flushing after sampling. One set of brine samples could not be collected because the brine sample line became completely clogged. Clogging may not be a problem for a full-scale PO*WW*ER™ system because the brine transfer lines will be larger.

These are minor operational problems that do not affect the system's reliability but should be considered in the design of a full-scale PO*WW*ER™ system.

3.4.4 Personnel Requirements

According to the developer, operation of the PO*WW*ER™ system requires two persons per shift for 2 weeks during startup, and one person per shift during normal operations. During the SITE demonstration, one operator and one technician were on site at all times. The operator manually recorded hourly temperature, tank level, and evaporator level readings. The technician was available in case of an emergency and to make minor modifications to the system. Personnel requirements are expected to be low at full-scale PO*WW*ER™ system installations because full-scale systems will be equipped with interfaced automatic monitoring and recording devices and safety shutdown controls.

3.5 Short-Term Impact

The potential short-term impact of PO*WW*ER™ system application involves worker safety and potential community exposures. Personnel operating the PO*WW*ER™ system and performing remedial activities are required to have health and safety training. With proper operation and monitoring of the PO*WW*ER™ system, community exposure should be minimal. Worker safety and potential community exposure are discussed below.

3.5.1 Worker Safety

Personnel operating the PO*WW*ER™ system at a Superfund or RCRA corrective action site are subject to OSHA regulations. Specific health and safety issues will vary depending on physical site hazards and the type of contamination present at a site. Therefore, a site-specific health and safety plan should be prepared.

General site hazards during the operation of a PO*WW*ER™ system include the following: (1) occupational noise exposure; (2) potential slip, trip, or fall hazards; (3) potential for contact with mechanical equipment **(for example,** motors) and electrical equipment; and (4) potential burn hazards (for example, during brine or product condensate sampling or in the event of a line rupture). Potential exposure to contaminants involves inhaling, absorbing, ingesting, and dermal contact with contaminants of concern. During the SITE demonstration, contaminants of concern included PCE, vinyl chloride, phenol, and methyl ethyl ketone (2-butanone). Samplers were required to wear modified Level C personal protective equipment and were monitored for heat stress.

3.5.2 Potential Community Exposure

Potential community exposure to health hazards associated with the operation of PO*WW*ER™ technology include exposure to (1) noncondensible vent gas emissions, (2) potential spills resulting from waste brine or product condensate handling, and (3) noise from the operation of the PO*WW*ER™ system. A full-scale PO*WW*ER™ system that is operating properly and regularly monitored and maintained should pose a minimal potential for community exposure.

3.6 Long-Term Effectiveness

The PO*WW*ER™ system evaporates andeffectively oxidizes volatile organic and inorganic contaminants in the catalytic oxidizer. Therefore, the PO*WW*ER™ system treats various aqueous wastes permanently. However, brine, which is a treatment residual, requires proper off-site treatment and disposal. Long-term effectiveness of the PO*WW*ER™ system was assessed based on the permanence of the treatment and the handling of process residuals. These factors are discussed below.

3.6.1 Permanence of Treatment

The PO*WW*ER™ system evaporates and permanently removes contaminants from aqueous wastes. During each 9-hour demonstration test run, the PO*WW*ER™ system produced approximately 92 gallons of product condensate. Product condensate from each test run was temporarily stored on site before being disposed of. The product condensate contained nondetectable amounts of VOCs, SVOCs, ammonia, and cyanide. The PO*WW*ER™ system removed sources of toxicity in the feed waste, such as metals, VOCs, SVOCs, ammonia, and cyanide. However, pH, hardness or salinity, and temperature of the product condensate were outside the optimum range for survival of acute toxicity test organisms. Therefore, the above-mentioned parameters may need to be adjusted to produce a product condensate that does not adversely affect aquatic life, if the product condensate is to be discharged to a surface water.

The pH of the product condensate ranged from 3.83 to 4.27. The acidic pH of the product condensate possibly resulted from the hydrolysis of NO_x produced in the catalytic oxidizer. This hypothesis is discussed further in Appendix B.

3.6.2 Residuals Handling

The only residual generated from the PO*WW*ER™ process is brine. The long-term effectiveness of the PO*WW*ER™ system ultimately depends on the treatment and disposal of brine. During the SITE demonstration, brine from the PO*WW*ER™ system was wasted once each 9-hour test period. The amount of brine wasted may vary depending on the TS concentration in the feed waste. Also, the contaminant characteristics of the brine are a function of the contaminant concentrations in the feed waste. Ultimate treatment and disposal of the brine depends on the types and concentrations of contaminants present. The brine produced during the SITE demonstration exhibited one hazardous waste characteristic-toxicity-and potentially could exhibit the hazardous characteristic of reactivity. Both of these characteristics **are** discussed below:

Toxicity

Based on the results of the toxicity characteristic leaching procedure (TCLP) test for metals, brine, which is an   hazardous waste, also exhibits the

characteristic of a DO04 hazardous waste because it contains TCLP arsenic at concentrations ranging from 34,400 to 103,000 μg/L. These concentrations are greater than the regulatory level of 5,000 μg/L.

Brine stabilization for subsequent disposal was not evaluated during the SITE demonstration. However, case study results evaluated by CWM show that after brine was stabilized, all extraction procedure (EP) toxicity levels for metals met their respective regulatory levels.

Reactivity

Brine produced during the SITE demonstration contained cyanide at concentrations ranging from 17 to 150 mg/L. If brine is exposed to acidic pH conditions, toxic hydrogen cyanide gas may be generated.

3.7 Factors Influencing Performance

Factors that may affect the performance of the PO*WW*ER™ system in meeting evaluation criteria include waste characteristics and operating parameters. Each of these factors is discussed below.

3.7.1 Waste Characteristics Influencing Performance

Waste characteristics influencing the PO*WW*ER™ system's performance include: (1) feed waste pH, (2) ionic strength, (3) contaminant loading, (4) nature of contaminants in the feed waste, (5) catalytic poisons, and (6) foaming. Each of these characteristics is discussed below:

Feed Waste pH

Feed waste pH affects the evaporation of inorganic contaminants because it determines their chemical speciation. Feed waste pH is more important when more than one volatile inorganic contaminant is present and when each volatile inorganic contaminant volatilizes at a different pH range.

For example, in solution, HCN exists either as HCN or cyanide (CN-) species depending on the solution pH. HCN is a volatile inorganic acid that predominates at pH values less than 9. Case study results show that cyanide was effectively stripped from the brine by acidifying the brine to cause the release of HCN.

Ammonia (NH3) in solution exists either as NH, or as an ammonium ion (NH4+). Ammonia is a volatile compound that predominates at pH values greater than 9. Case study

results show that less ammonia was evaporated from the **brine at pHs of 7 to 8 than at pH 11.**

Ammonia and cyanide also form complexes with metals present in aqueous wastes. Aqueous waste pH can also affect the stability of ammonia and cyanide metal complexes, which ultimately determines the ammonia and cyanide removal efficiency.

Aqueous waste pH may also determine the corrosivity characteristics of the waste. According to CWM case studies, when corrosive material is to be treated, the PO*WW*ER™ system may need to be constructed of corrosion resistant material.

Ionic Strength

The ionic strength of an aqueous waste is a measure of the concentration and the charge of ionic species present. High ionic strength of an aqueous waste can cause a phenomenon known as "salting-out effect." Because of this phenomenon, increasing ionic strength can cause a decrease in the solubility of molecular species such as VOCs and SVOCs, thus increasing their evaporation efficiency (Snoeyink and Jenkins, 1980). According to CWM, during bench-scale studies, sodium chloride was added to aqueous wastes to increase ionic strength and the evaporation efficiency of organic contaminants present.

Contaminant Loading

Total contaminant loading may affect the performance of the PO*WW*ER™ system. For some applications, it may determine the PO*WW*ER™ system's applicability.

Contaminant loading determines the amount, rate, and characteristics of the brine produced. Brine is removed from the evaporator when it reaches a specific temperature corresponding to a specific BPR. BPR is the difference between the boiling point of a solution and the boiling point of water at the same pressure. BPR is associated with a specific brine concentration. During the SITE demonstration, BPR was not determined (see Section 3.8 for details). The evaporator BPR is an important operating parameter because it determines contaminant removal efficiencies.

Total contaminant loading may also affect the concentration levels of contaminants in the brine and may result in slight increases in contaminant concentrations in the noncondensible vent gas. SITE demonstration results show that an increase in total contaminant loading may

result in slight increases in contaminant concentrations in the noncondensible vent gas and in reduced VOC evaporation efficiency. Also, SITE demonstration and case study results show that the PO*WW*ER™ system can treat wastes with high total organic and inorganic contaminant loading without any measurable effect on product condensate quality.

Nature of Contaminants in the Feed Waste

SITE demonstration and other case study results show that volatile organic and inorganic contaminants are effectively evaporated from the brine and successfully oxidized in the catalytic oxidizer. However, nonvolatile contaminants, such as certain SVOCs, metals, and other inorganic contaminants, remained in the brine.

Higher molecular weight hydrocarbons are more easily oxidized than those with lower molecular weights. Catalytic reactivity also varies with molecular structure, increasing in the following order: aromatic hydrocarbons, branched paraffins, normal paraffins, olefinic hydrocarbons, acetylenic hydrocarbons (Wark and Warner, 1981).

Catalytic Poisons

Deposition of particulates on the surface of a typical catalyst bed decreases the available surface area for catalytic action. This decrease lowers the effectiveness of the catalyst and its operating life. The normal operating life of a catalyst without particulate deposition problems may be from 3 to 5 years. One other problem associated with catalytic oxidation is poisoning of the bed by specific contaminants in the waste gas. Materials such as iron, lead, silicon, and phosphorous shorten the lives of many catalysts. Sulfur compounds may also suppress the effectiveness of some catalysts (Wark and Warner, 1981).

The catalyst used in the PO*WW*ER™ system oxidizer is the main innovative feature of the system. The catalyst is a proprietary nonprecious metal oxide catalyst in a specific support medium. According to CWM, the catalyst is not as expensive or limited in versatility as a precious metal catalyst and was designed to withstand problems common to precious metal catalysts such as fouling, particulate deposition, activity suppression and poisoning. However, 'because of the nature of the catalyst, periodic make-up is required.

Foaming

Depending on the nature of the feed waste, foaming may occur in the vapor body. If foaming is not controlled, foam can pass through the mesh pad, leave deposits in the oxidizer, plug the catalyst tray, and contaminate the product condensate. An antifoaming agent can be added to the feed waste to prevent vapor body foaming. In addition, the vapor body is equipped with a foam alarm that is activated if the foam reaches a certain level in the vessel. If the alarm is activated, antifoaming agent can be injected directly over the foam in the vapor body until foaming subsides.

3.7.2 Operating Parameters Influencing Performance

Operating parameters that may influence the PO*WW*ER™ system's performance include (1) feed waste flow rate, (2) ratio of propane (or other fuel) flow rate to air flow rate, (3) excess air, (4) catalyst bed depth, and (5) heat transfer coefficients. Each of these parameters is discussed below.

Feed Waste Flow Rate

The feed waste flow rate determines the mass loadings on the individual components of the PO*WW*ER™ system. Mass loading determines the treatment time required and the treatment efficiency that can be achieved.

Ratio of Propane (or Other Fuel) Flow Rate to Air Flow Rate

This parameter affects the oxidizer temperature, which in turn affects the oxidation efficiency and the formation of oxidation byproducts. Case study results also show that increased treatment temperature results in increased oxidation efficiency.

Literature data indicate that the oxidation temperatures for the following solvents range from 500 to 850°F: toluene, methyl ethyl ketone (2-butanone), xylene, and alcohols. The oxidation temperature required for exhaust gas from chemical processes ranges from 400 to 750 °F. Typical examples of contaminants present in the exhaust gas from chemical processes include CO, ethylene, ethylene oxide, and propylene (Wark and Warner, 1981). Most catalysts have an upper limit in their operating temperature range, which for many is around 1,500 °F. During the SITE demonstration, propane was used as fuel for the oxidizer burner.

Excess Air

The percent of excess air added to the oxidizer affects oxidation efficiency and the oxidation products formed. The rate of oxidation of a hydrocarbon is proportional to

the concentration of that hydrocarbon in the gas stream if at least 2 percent oxygen by volume is present in excess of that required for complete oxidation (Wark and Warner, 1981). At an oxygen level greater than 30 percent of the stoichiometric requirement, a removal efficiency of greater than 99 percent was achieved. If hydrocarbons are only partially oxidized, a considerable amount of CO may be formed.

Catalyst Bed Depth

The catalyst bed depth may affect oxidation efficiency because it determines the contact time between the catalyst and the vapor stream. The oxidation efficiency of several organic and inorganic compounds is a function of residence time. Current practice indicates that 85 to 95 percent conversion of pollutants typically requires 2.0 cubic feet (ft^3) of catalyst for each 10^6 standard cubic feet per minute (scfm) of gas (Wark and Warner, 1981).

Heat Transfer Coefficients

The physical-chemical characteristics of the brine may have a fouling effect on the heat transfer surfaces. Periodic system cleaning may be required to maintain high heat transfer coefficients (see Appendix C). During the SITE demonstration, heat transfer coefficients were not determined (see Section 3.8 for details).

3.8 Evaluation Limitations

Two major limitations that restricted evaluation of the PO*WW*ER™ system's performance were testing limitations and confidential information limitations. These limitations were imposed by CWM, mostly for protection of proprietary know-how. Each of these limitations is discussed below.

3.8.1 *Testing Limitations*

Testing limitations include sampling and monitoring location limitations and spiking compound and spiking concentration limitations. Both of these limitations are discussed below.

Sampling and Monitoring Location Limitations

During the SITE demonstration, CWM allowed only four peripheral locations on the PO*WW*ER™ system to be sampled and monitored. However, these locations did not include several locations within the PO*WW*ER™ pilot plant process, such as before and after the catalytic oxidizer. Also, the monitoring parameters recorded during the demonstration were only those approved by CWM. These parameters did not include several key parameters such as BPR, oxidizer temperature, and heat transfer coefficients. According to CWM, by analyzing samples taken within the PO*WW*ER™ pilot plant process, monitoring additional locations, and recording values of key parameters within the system, proprietary information about the PO*WW*ER™ system may be disclosed to the public.

Spiking Compound and Spiking Concentration Limitations

CWM limited the spiking compounds and concentrations used during the SITE demonstration. According to CWM, spiking with additional proposed compounds (for example, aromatics such as benzene) or at concentrations different from those permitted by CWM during the SITE demonstration would not be allowed because of health and safety concerns to individuals at the LCTC site and the possibility of changing the residual waste characteristics to the extent that the LCTC site would violate its hazardous waste operating permit.

3.8.2 *Confidential Information Limitations*

CWM provided reports that summarize case study results. However, several sections of the reports are classified as confidential by CWM, and the information was therefore deleted from these reports. Consequently, only select information is available regarding the PO*WW*ER™ system's performance in the case study reports.

Section 4
Economic Analysis

This section presents cost estimates for using a 50-gpm **PO*WW*ER™** system to treat landfill leachate at a Superfund site. Cost estimates presented in this section are based primarily on data compiled from the developer of the technology and partly on the SITE demonstration at the LCTC site. Costs have been placed in 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans, 1990). Costs are presented in January 1993 dollars and are considered to be order-of-magnitude estimates with an accuracy of plus 50 percent and minus 30 percent.

Table 4-l presents a breakdown of costs for the 12 categories. The table presents fixed costs and annual variable costs, the total costs and net present values for a H-year and 30-year leachate remediation project, and costs per 1,000 gallons of leachate treated. Site-specific factors affecting costs, the basis of this economic analysis, and the 12 cost categories are discussed in the following sections. A summary of the economic analysis is also presented at the end of this section.

4.1 Site-Specific Factors Affecting Costs

A number of factors affect the estimated costs of treating landfill leachate with the **PO*WW*ER™** system. Factors affecting costs generally include physical site conditions, geographical site location, treatment goals, leachate characteristics, and the total volume of leachate to be treated.

The cost data presented in this analysis were primarily provided by the technology developer. Certain operating conditions could not be monitored during the SITE demonstration (see Section 3.8 for details). As a result, many operating parameters could not be independently verified or quantified.

4.2 Basis of Economic Analysis

The PO*WW*ER™ technology can treat several types of aqueous wastes, including landfill leachate, contaminated ground water, and industrial wastewater. Landfill leachate has been selected for this economic analysis because it represents a waste commonly found at Superfund and RCRA corrective action sites, and because it is a waste whose treatment involves most of the cost categories.

This analysis assumes that the **PO*WW*ER™** system will treat landfill leachate on a continuous basis 24 hours per **day,** 7 days per week, 365 days per year, and will be on-line 90 percent of the time. Based on this assumption, a 50-gpm **PO*WW*ER™** system can annually treat about 24 million gallons. Because most landfill leachate remedial projects are characteristically long term, this analysis compares the costs of operating the system for 15 and 30 years in Table 4-l.

Other assumptions used for this analysis include the following:

- The site is a Superfund landfill located near a large municipality in the Gulf Coast Region of the United States.

- No pretreatment of the feed waste is required.

- An access road, utilities, and a sewer line need to be extended to the **PO*WW*ER™** system site.

- A 1,000-square-foot storage building is needed for supplies, laboratory equipment, office space, and sanitary facilities.

- A natural gas, engine-driven, electric generator will be installed as an emergency power source.

- About 200 gallons per day (gpd) of potable water are required.

- The treatment system is constructed of suitable material and operates automatically.

Table 4-1. Costs Associated with the PO*WW*ER™ Technology

Cost Categories	Estimated Costs (1993 Dollars)
Site Preparation"	$1,100,000
Permitting and Regulatory Requirements"	200,000
Capital Equipment"	4,200,000[b]
Startup"	55,000
Labor"	230,000
Consumables and Supplies"	28,000
Utilities"	480,000
Effluent Treatment and Disposal[d]	0
Residual and Waste Shipping and Handling"	2,300,000
Analytical Services[c]	42,000
Maintenance and Modifications"	200,000
Demobilization"	70,000
Total One-Time Costs	$5600,000
Total Annual O&M Costs	$3,300,000
Total Cost of 1 5-Year Project[e,f,g]	$80,000,000
Total Cost of 30-Year Project[e,f,h]	$240,000,000
Net Present Value of 15-Year Project'	$37,000,000
Net Present Value of 30-Year Project'	$52,000,000
Costs per 1,000 Gallons Treated (15 Years)]	$100
Costs per 1,000 Gallons Treated (30 Years)[j]	$73

Notes:
[a] One-time costs
[b] Capital equipment cost for a modular 50-gpm PO*WW*ER™ system, installed and assembled on a turnkey basis, is $4 million.
[c] Annual O&M costs
[d] Not applicable
[e] Annual inflation rate assumed to be 5 percent
[f] Capital equipment not discounted over term of project
[g] For a 15-year project, a 50-gpm PO*WW*ER™ system will treat a total of 360 million gallons.
[h] For a 30-year project, a 50-gpm PO*WW*ER™ system will treat a total of 720 million gallons.
[i] Net present value discounted at annual rate of 10 percent
[j] Presented in terms of a net present value.

- One technician per shift is required to monitor the equipment, collect all required samples, and perform equipment maintenance and minor repairs.

- Almost all of the product condensate will be discharged to a POTW; the remainder will be used on-site as process make-up water.

- Product condensate requires pH adjustment from 4 to greater than 6.

- The catalytic oxidizer operates in a fluidized bed mode requiring the periodic addition of make-up catalyst to compensate for attrition losses.

- Treated and untreated leachate samples will be collected once every month and analyzed off site for VOCs, SVOCs, and metals to monitor system performance.

- Waste brine from the treatment system is considered a hazardous waste and requires off-site stabilization and disposal at an approved disposal facility.

- Labor costs associated with major equipment repairs or replacement are not included.

4.3 Cost Categories

Cost data associated with the PO*WW*ER™ technology have been assigned to the following 12 categories: (1) site preparation; (2) permitting and regulatory requirements; (3) capitalequipment; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residuals and waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization. Costs associated with each of these categories are discussed below.

4.3.1 Site *Preparation Costs*

Site preparation costs include administrative, construction, and mobilization costs. For this analysis, administrative costs such as legal searches, access rights, and other site planning activities are estimated to be $50,000.

Construction costs include (1) construction of a roofed structure with concrete foundations, equipment pads, sumps, and secondary containment curbs to house the PO*WW*ER™ system and liquid storage tanks; (2) construction of a storage building; (3) construction of an access road; (4) construction of a leachate collection system including all required pumps and piping; and (5) extension of all necessary utility lines such as electric, natural gas, sewer, and water lines to the treatment system site.

This analysis assumes a 3,000-foot access road will be constructed from a main thoroughfare to the PO*WW*ER™ system. The road will be either asphalt or concrete and will be 16 feet wide. The total cost for this road will be approximately $240,000.

The PO*WW*ER™ system will be installed on reinforced concrete foundations inside an open, roofed structure with sumps and secondary containment curbs. These reinforced concrete foundations will occupy approximately 4,000 square feet. The total cost for the foundations and structure will be about $150,000.

A 1,000-square-foot storage building will be required for storage of supplies and laboratory equipment and for office space and sanitary facilities. The building will be a prefabricated metal structure and will be located next to the PO*WW*ER™ system. The total cost for this storage building will be approximately $80,000.

This analysis assumes a leachate collection system will be installed to collect and convey leachate to the PO*WW*ER™ system. The leachate collection system will consist of a leachate collection trench with perforated piping and a leachate sump equipped with two pumps and all required piping, valves, and controls to transfer the leachate to the PO*WW*ER™ system. The total cost of installing the leachate collection system is approximately $150,000.

Electrical power, natural gas, sewer, and water lines will be extended to the treatment system. It is assumed that these lines will be installed alongside the access road. Installation of overhead electrical power costs about $25,000 per 1,000 feet of line for a total cost of $75,000; installation of required transformers is estimated to be $50,000. Installation of natural gas pipeline costs about $20,000 per 500 feet for a total cost of $120,000. Potable water lines to be connected to the storage building are estimated to cost about $15 per linear foot for a total cost of $45,000. An 8-inch-diameter sewer line for discharging product condensate and sanitary water is estimated to cost $40 per linear foot for a total cost of approximately $120,000. The total cost of extending utilities to the PO*WW*ER™ system is $410,000.

Mobilization involves transporting the entire PO*WW*ER™ treatment system to the site. AR1 Technologies, Inc. (ARI), the technology licenser, will deliver the system from the Chicago area. For this analysis, the site is assumed to be located in the Gulf Coast Region. The total estimated mobilization cost is about $50,000.

Total site preparation costs, rounded to two significant figures, are estimated to be $1,100,000.

4.3.2 *Permitting and Regulatory Requirements costs*

Permitting and regulatory costs vary depending on whether treatment is performed at a Superfund site or a RCRA corrective action site and how treated effluent and solid wastes are disposed of. Superfund sites also require remedial actions to be consistent with ARARs including environmental laws, ordinances, regulations, and statutes **for** federal, state, and local standards andcriteria. In general, ARARs must be determined on a site-specific basis. RCRA corrective action sites require additional monitoring records and sampling protocols that can increase the permitting and regulatory costs by an additional 5 percent.

Permitting and regulatory costs are assumed to be about 5 percent of the total capital equipment costs for this treatment operation, which is assumed to be part of a Superfund remedial action. The annual discharge permit to a POTW is included in this estimate. For this analysis, total permitting and regulatory costs are estimated to be $200,000.

4.3.3 Capital Equipment Costs

Capital equipment costs include purchasing the PO*WW*ER™ treatment system and emergency power source equipment. ARI estimates that the cost for a 50-gpm PO*WW*ER™ treatment system is about $4 million. ARI includes the following elements in the turnkey costs of purchasing each PO*WW*ER™ treatment system:

- Complete PO*WW*ER™ treatment system, including a scrubber (see Section 2 **for** description)

- Treatability study to determine the appropriate treatment specifications

- System design costs

- Assembly of the system including all interconnecting piping, controls, and utilities

- All necessary tanks including the waste feed tank, chemical feed system for pH adjustment, and metering pumps

- On-line installation of effluent monitoring equipment, including CEM, to measure all critical parameters

A natural gas, engine-driven emergency generator will be required to provide uninterrupted electric power to the system. The cost for installing the emergency generator, automatic transfer switch, and all required appurtenances is estimated to be $200,000.

Total capital equipment costs are estimated to be $4,200,000.

4.3.4 Startup Costs

Startup costs include all activities required to make the PO*WW*ER™ system fully operational. These costs include initial operator training and optimization and shakedown costs. ARI will provide personnel to assist with startup activities.

Initial operator training is needed to ensure safe and economical operation of the treatment system. ARI provides O&M training as part of the costs of purchasing the treatment system. However, a 40-hour health and safety training course is needed for each operator. Total startup training costs, which also include developing a health and safety program, are estimated to be $25,000.

Optimization and shakedown activities include initial startup, trial runs, and final equipment inspection. ARI estimates that these activities require 2 weeks to complete and that total optimization and shakedown costs will be approximately $30,000.

Total startup costs are estimated to be about $55,000.

4.3.5 Labor Costs

Labor costs include the following: total staff needed for O&M of the PO*WW*ER™ system; annual health and safety training refresher courses; and demobilization costs, which are discussed in Section 4.3.12. The labor wage rates provided in this analysis include fringe benefits. Once the system is functioning, it is assumed that it will operate continuously at the designed flow rate.

Three 8-hour shifts will be worked each day, 7 days per week. Each shift will require one technician earning $18 per hour and one supervisor who will work during the first shift only and earn $22 per hour. The operator will monitor the equipment, perform routine maintenance, and perform routine sample collection. This analysis assumes a total of five workers rotating shifts to allow for weekends and vacations. Total annual labor costs, rounded to two significant figures, are estimated to be about $220,000.

Annual health and safety training refresher courses will cost about $2,000 per person for a total annual cost of about $10,000.

Total annual labor costs, rounded to two significant figures, are estimated to be $230,000.

4.3.6 Consumables and Supplies Costs

Consumables and supplies costs include oxidizing catalyst replenishment and purchase of antifoaming agents, sodium hydroxide, personal protective equipment, and personal protective equipment disposal drums. Costs of these items are discussed below.

About 2 to 4 percent of the initial catalyst bed volume will need replenishment every month. **ARI** estimates about 85 pounds of catalyst are needed per month. According to ARI, catalyst costs about $1.025 per pound. **ARI** will provide the proprietary nonprecious metal catalyst. Total annual catalyst replenishment costs are estimated to be about $1,100.

Antifoaming agents may be needed to reduce the amount of foam generated during treatment. About 0.5 gallon of antifoaming agent was used for every 1,000 gallons of leachate treated during the SITE demonstration. Assuming the same usage rate and operating 90 percent of the time, the 50-gpm **PO*WW*ER™** system will require about 12,000 gallons of antifoaming agent annually. It is assumed that antifoaming agent will be ordered when needed and stored on site in a 500-gallon tank. The costs of the tank and its feed system are provided in the cost of purchasing the **PO*WW*ER™** system (see Section 4.3.3, Capital Equipment Costs). The antifoaming agent cost provided by **ARI** is about $1.85 per gallon. Total annual antifoaming agent costs are estimated to be $23,000.

This analysis assumes sodium hydroxide will need to be added to the product condensate to adjust the pH from 4 to greater than 6 in order to meet POTW discharge requirements. Approximately 65 gallons of sodium hydroxide per year will be used. Sodium hydroxide is commercially available in a 50-percent solution for about $1.50 per gallon. Based on this estimate, annual sodium hydroxide usage would cost approximately $200.

Personal protective equipment (PPE) typically consists of nondisposable and disposable equipment. Nondisposable equipment consists of hard hats, steel-toed boots, and full-face air respirators. Disposable personal protective equipment includes Saranax- or Tyvek-type coveralls, latex inner gloves, nitrile outer gloves, and safety glasses. Disposable personal protective equipment will be worn during sample collection only. Annual personal protective equipment costs are estimated to be about $3,000.

PPE is assumed to be hazardous and will need to be disposed of in 24-gallon fiber drums. Any other potentially hazardous wastes will also be disposed of in these drums. One drum is assumed to be filled every 2 weeks. Drums cost about $12 each for a total annual cost of about $300. Disposal of the drums is discussed in Section 4.3.9, Residuals and Waste Shipping and Handling Costs.

Total annual consumables and supplies costs are estimated to be $28,000.

4.3.7 Utilities Costs

Total utilities costs are based on electricity, natural gas, and water used to operate the **PO*WW*ER™** system, its auxiliary equipment, and the storage building. It is also assumed that the system will be operating at 90 percent of the time. Actual costs vary depending on the site's geographical location and local utility rates. These cost estimates assume flat utility rates and no monthly charges.

According to ARI, the 50-gpm **PO*WW*ER™** system uses about 445 kilowatts and would use about 3.9 million kilowatt-hours (kWh) annually. This analysis assumes that electricity costs about $0.10 per kWh and that any auxiliary equipment draws an additional 10 percent of the total annual electrical power of the **PO*WW*ER™** system. Total annual electrical costs would therefore be approximately $390,000.

According to ARI, the 50-gpm **PO*WW*ER™** system uses about 2,200 standard cubic feet per hour (scfh) of natural gas. This analysis assumes that natural gas costs about $0.50 per 1,000 therms, With the system operating 90 percent of the time, total annual natural gas costs would be approximately $90,000.

Approximately 200 gpd of water will be required for cleanup and sanitary uses. This analysis assumes that water costs $1.50 per 1,000 gallons. Total annual water costs will be about $100.

Total annual utility costs, rounded to two significant figures, are estimated to be about $480,000.

4.3.8 Effluent Treatment and Disposal Costs

Effluent from the **PO*WW*ER™** system includes product condensate and noncondensible gases generated during the scrubbing and condensing stage. For this analysis, product condensate is assumed to need pH adjustment and will be discharged to a POTW. The costs associated with treating effluent are discussed in Section 4.3.6, Consumables and Supplies Costs. The costs of discharging effluent to a POTW are discussed in Sections 4.3.1, Site Preparation, and 4.3.2, Permitting and Regulatory Requirements. It **should** be noted that the Gulf Coast Region is topographically flat and the discharge to the POTW is assumed to be by gravity flow. If one or more pump stations are needed to

convey the product condensate and sanitary flow to the POTW, effluent treatment anddisposal costs will be higher.

Noncondensible gases will be monitored but are assumed to meet local and regional emissions requirements and will be released to the atmosphere. This release is also assumed to not require an air permit. The costs of air monitoring equipment are included in the cost of purchasing the PO*WW*ER™ system (see Section 4.3.3, Capital Equipment).

4.3.9 Residuals and Waste Shipping and Handling Costs

Waste brine and personal protective equipment drums are the only wastes generated from operating the PO*WW*ER™ system. These wastes are considered hazardous and require disposal at a permitted facility. Waste disposal costs include transportation, stabilization, and landfill disposal. The cost estimates discussed below do not include approval fees, state taxes, or state landfilling permits.

The waste brine is required to be disposed of off site as a hazardous waste. To minimize storage costs, this analysis assumes that waste brine can be transferred by gravity directly from the PO*WW*ER™ system into a 6,000-gallon tanker truck parked on site. This analysis also assumes that for a full-scale PO*WW*ER™ system operating on a continuous basis, about 3 gallons of brine would be generated for every 100 gallons of leachate treated (approximately 3 percent of the feed volume). At this rate, the 50-gpm flow-rate system will generate about 720,000 gallons of brine per year, or about 60,000 gallons per month. This analysis further assumes that the wastes will be shipped 100 miles to the nearest RCRA-permitted treatment and disposal facility. Transportation costs for the waste brine are estimated to be about $700 per 6,000-gallon tanker. At a RCRA-permitted facility, brine can be stabilized by solidification and disposed of at a cost of about $3 per gallon. Total annual brine disposal costs will be about $2.2 million.

This analysis also assumes that the cost of shipping, handling, and transporting the personal protective equipment drums to a hazardous waste disposal facility are about $1,000 per drum. Total annual drum disposal costs are estimated to be $26,000.

Total annual disposal costs, rounded to two significant figures, are estimated to be about $2,300,000.

4.3.10 Analytical Services Costs

Analytical costs include laboratory analyses, data reduction and tabulation, QA and QC, and reporting. This analysis assumes that one sample of treated and untreated leachate will be collected each month to be analyzed for VOCs, SVOCs, and metals. Monthly laboratory analyses will cost about $3,000; data reduction, tabulation, QA/QC, and reporting are estimated to cost a total of about $500 per month.

A treatability study will need to be performed to determine the appropriate specifications of the PO*WW*ER™ system. The cost of purchasing the PO*WW*ER™ system includes the cost of the treatability study.

Total annual analytical services costs are estimated to be about $42,000.

4.3.11 Maintenance and Modifications Costs

ARI estimates that maintenance and modifications costs for the PO*WW*ER™ treatment system will be low because the system does not have many moving parts and is not expected to be shutdown for routine maintenance. However, the extreme heat generated by the system may affect maintenance requirements.

This analysis assumes that annual maintenance costs will be about 5 percent of capital equipment costs, which is about $200,000.

4.3.12 Demobilization Costs

Site demobilization will include shutdown, disassembly, transportation, and disposal of all equipment to alicensed hazardous waste disposal facility. Site cleanup, building decontamination, and site restoration costs will also be incurred during demobilization. This analysis assumes the storage building will remain on site. Total demobilization is estimated to take about 1 week to complete and will cost about $70,000, including labor.

The costs of demobilization, however, will occur at the end of the remediation project. Therefore, based on the annual inflation rate of 5 percent, the net future values of this cost for a 15-year project and 30-year project are estimated to be $140,000 and $300,000, respectively. These costs are rounded to two significant figures and were used to calculate the total costs of the 15-year and 30-year projects presented in Table 4-l.

4.4 Summary

This economic analysis presents the costs associated with a 50-gpm PO*WW*ER™ system treating landfill leachate at a Superfund landfill site. The costs associated with this project are presented in Table 4-l.

Total estimated one-time costs are about $5.6 million. Of this $5.6 million, $4 million are for purchasing the PO*WW*ER™ system. Total annual O&M costs are estimated to be about $3.3 million and reflect a 90 percent on-line factor. Waste disposal costs account for about 70 percent of annual O&M costs.

A remediation project lasting 15 years would treat about 360 million gallons of leachate at an estimated total cost of $80 million. The total net present value of this project would be about $37 million, which results in a cost of about $100 per 1,000 gallons of leachate treated. A remediation project lasting 30 years would treat about 720 million gallons of leachate at an estimated total cost of $240 million. The total net present value of this project would be $52 million, which results in a cost of about $73 per 1,000 gallons of leachate treated.

As mentioned earlier, costs presented in this analysis are order-of-magnitude estimates (plus 50 percent to minus 30 percent) and are rounded to two significant figures.

Section 5
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Appendix A
Developer's Claims for the PO*WW*ER™ Technology

A.1 Developer's Claims

This appendix summarizes claims made by the developer, Chemical Waste Management, Inc. (CWM), regarding the PO*WW*ER™ system. The information presented herein represents the developer's point of view and does not constitute U.S. Environmental Protection Agency (EPA) approval or endorsement of the statements made in this appendix.

A.l.1 Introduction

Complex industrial and hazardous wastewaters containing mixtures of inorganic salts, metals, volatile and semivolatile organics, volatile inorganics, radionuclides, and other compounds, pose a challenge to engineers of treatment systems. These wastewaters differ greatly from one another and change characteristics during the course of operation. Treatment standards also change, requiring engineers to anticipate future requirements.

The conventional treatment approach has been to integrate a number of unit operations in a treatment train specifically designed for a particular wastewater after conducting elaborate treatability studies. The treatment train requires constant monitoring and adjustment to ensure proper operation of each unit in the train. This approach is operation and maintenance intensive.

The PO*WW*ER™ technology treats complex industrial and hazardous wastewaters in a single integrated system. The technology is flexible enough to accommodate wide variations in wastewater composition and is operator friendly because it does not require constant monitoring and adjustment. This patented, proprietary technology was developed over an 8-year period and uniquely combines evaporation with catalytic oxidation to concentrate the nonvolatile contaminants in a residual brine stream of very small volume. The technology also catalytically oxidizes volatile contaminants. Most wastewater is converted into high-quality water that can be reused or discharged and that

meets not only today's treatment standards but also foreseeable future requirements. This technology has been tested and well demonstrated on a number of complex wastewaters through the operation of fully integrated pilot plants. PO*WW*ER™ is now used commercially to treat a variety of industrial and hazardous wastewaters.

A.1.2 Technology Description

The PO*WW*ER™ technology combines evaporation with catalytic oxidation in a flexible, easy to operate system. A PO*WW*ER™ based wastewater treatment facility can generally be designed with a minimal upfront treatability effort and once built, can handle significant variations in wastewater composition. The **system does** not require expensive constant monitoring and operates unattended. Table A-l summarizes some capabilities of the PO*WW*ER™ system.

A.1.3 Benefits

Besides being flexible, easy to operate, and uniquely accommodating significant variations in wastewater composition, the PO*WW*ER™ technology offers the following specific advantages:

- Treats a wide spectrum of aqueous wastewater, and system components are not affected by any unexpected contaminants

- Produces high-quality water that can be used as boiler feed water makeup, cooling tower makeup, or high-quality process water, saving the cost of expensive treatment in all cases

- Destroys the organic pollutants reducing overall pollution to the environment

- Achieves high volume reduction by minimizing the volume of waste for final disposal

Table A-1. Capabilities of PO*WW*ER™

Specific Capabilities of PO*WW*ER™	Demonstrated Results	Comparison to Conventional Technology
High volume reduction of waste materials	Concentrates wastewaters from 0.5% to 65% total solids, providing a volume reduction of 130 to 1 with no pretreatment requirements	Reverse Osmosis: limited to 7 to 8% total solids and requires substantial pretreatment; volume reductions of only 15 to 1 typical.
High removal efficiency for organic pollutants	Routinely removes 99% of all organic compounds; higher removals achieved for specific pollutants (for example, 99.99% for toluene)	Biological Treatment: limited to 95 to 98% for biologically degradable compounds; others not removed
High removal efficiency for volatile inorganics	Generally removes 99% of ammonia and cyanide compounds	Stripping and oxidation: limited to equilibrium solubility at operating temperatures
High removal efficiency for heavy metals	Heavy metals separated by evaporation of wastewater; therefore, PO*WW*ER™ can achieve extremely high removal efficiencies	Precipitation: limited to solubility point of metallic species
Significant flexibility to handle changes in feed composition	System insensitive to changes in heavy metal concentration and only sensitive to changes in organic composition	General: Most systems cannot accommodate changes in feed composition and providing high-quality effluent
Minimal pretreatment required	Only possible pretreatment may be neutralization and control of foaming	General: comprehensive pretreatment may be required for sophisticated treatment processes

- Uses no chemicals except for pH adjustment or defoaming chemicals

- Can use waste energy to significantly improve cost economics

- Requires a small area, enabling the location of the technology next to processing plants, thus improving operating flexibility and saving valuable real estate.

A.1.4 *Applications*

PO*WW*ER™ technology is ideally suited for treatment and volume reduction of complex industrial and hazardous wastewaters containing mixtures of inorganic salts, metals, volatile and semivolatile organics, volatile inorganics, and radionuclides. The technology is particularly suited to wastewater that cannot be treated by a single conventional step and that requires a complex treatment train involving a number of unit operations.

A partial list of the contaminants and pollutants treatable by the PO*WW*ER™ technology are presented in Table A-2. The general ranges of contaminants and pollutants in wastewaters successfully treated by PO*WW*ER™ technology applications are presented below.

- Total Volatile Organics: 100 to 10,000 parts per million (ppm)
- Total Semivolatile Organics: 10 to 500 ppm
- Total Dissolved Solids: 0.25% to 15%
- Radioactive Contaminans: Up to 500 ppm

Examples of wastewaters that are good candidates for treatment by the PO*WW*ER™ technology include the following:

- Landfill leachates
- Lagoon waters
- Contaminated ground water
- Low-level radioactive mixed wastewaters
- Industrial wastewaters from chemical, petrochemical, steel, automobile, synthetic rubber, wood finishing, paint, and pulp and paper plants

Table A-2. Contaminants and Pollutants Treatable by PO*WW*ER™

Organic	Inorganic	Radioactive
Halogenated volatiles	Heavy metals	Plutonium
Halogenated semivolatiles	Nonmetallic toxic elements	Americium
Nonhalogenated volatiles	Cyanides	Uranium
Nonhalogenated semi-volatiles	Ammonia	Technetium
Organic pesticides and herbicides	Nitrates	Thorium
Solvents	Salts	Radium
Benzene, toluene, ethylbenzene, and xylenes		Barium
Organic cyanides		
Nonvolatile organics		

A.1.5 Design Options

The basic PO*WW*ER™ system consists of a forced circulation evaporator, an oxidizer, and an air-cooled condenser. The system is supplied in modular design for up to 50 gallons per minute of treatment capacity for easy installation and commissioning. Larger systems are provided as multiple units of modular construction or are designed for the required capacity for field construction and installation. A number of options are available to enhance the performance or improve the overall cost economics of the PO*WW*ER™ system for a given application. Some of these design options and their contributing benefits are listed in Table A-3. Depending on wastewater characteristics, costs of utilities, and availability of waste heat, one or more of these options may be incorporated to provide an optimum design for the application.

Table A-3. Design Options for the PO*WW*ER™ System

Option	Contributing Effect
Multi-effect Evaporator	Saves up to 50 to 70% energy consumptioncomparedtoasingleeffect evaporator
Mechanical Vapor Recompression Evaporator	Saves up to 50% energy consumption when reasonably priced electricity is available
Scrubber	Removes acid gases formed in the oxidizerwhen chlorinated hydrocarbons are present in the wastewater
Waste Heat Utilization	Improves cost economics depending upon the level and quantity of waste heat available

A.1.6 Cost Economics

The typical cost of a PO*WW*ER™ system with a 50 gallon per minute (gpm) treatment capacity that is completely assembled and installed on a turnkey basis is $4.0 million. Similarly, a 25 gallon per minute treatment capacity system costs $3.0 million.

Utilities required for these two system sizes are as follows:

	50 GPM	25 GPM
Electricity, Kilowatt hours per hour	445	275
Natural Gas, standard cubic feet per hour (scfh)	22,000	11,000

Total operating costs, which include utilities and minor additions of antifoam and catalyst agents, are less than $0.04 per gallon.

The above examples were estimated for a wastewater stream of landfill leachate treated in a PO*WW*ER™ system having a double effect evaporator. Other wastewater streams would have similar capital and operating costs.

A.2 Summary

The PO*WW*ER™ technology is an innovative, cost-effective, and flexible technology for treating industrial and hazardous wastewaters. The technology can treat wastewaters with varying complexities, changing characteristics, varying levels of contaminants, and different quantities of total dissolved solids.

A PO*WW*ER™ system produces high-quality effluent, destroys organic pollutants, and achieves very high volume reduction. This technology has been well demonstrated and is now commercially used to treat a variety of hazardous industrial wastewaters.

Appendix B
Site Demonstration Results

The Chemical Waste Management, Inc. (CWM), Superfund Innovative Technology Evaluation (SITE) demonstration was conducted in September 1992 at CWM's Lake Charles Treatment Center (LCTC) site in Lake Charles, Louisiana. This appendix briefly describes the LCTC site and technology demonstration testing and sampling procedures, and summarizes the SITE demonstration treatment results. References appear at the end of this appendix.

B.l Site Description

CWM's LCTC site is located near the cities of Sulphur and Lake Charles in the southwest comer of Louisiana. The LCTC site has facilities that include a hazardous waste landfill, a high-capacity stabilization unit, and drum managing and decanting facilities. CWM began operating the site's first hazardous waste disposal cell in 1980. Although CWM constructed and operated two sanitary landfills at the site during the early 1980s the company's primary focus remains hazardous waste treatment and disposal. The LCTC is capable of handling almost any type of liquid hazardous waste, including wastes containing organics, cyanide, sulfide, and other inorganics.

The PO*WW*ER™ pilot-scale plant located at the LCTC site has been operative since 1988. The PO*WW*ER™ pilot plant is used primarily as a demonstration unit for companies interested in testing the PO*WW*ER™ system's applicability to specific aqueous wastes. The PO*WW*ER™ system was originally developed to handle leachates from CWM's hazardous waste land disposal units, but it is currently being marketed for a variety of aqueous treatment applications.

B.2 Technology Demonstration Testing and Sampling Procedures

The objectives of the SITE demonstration of CWM's PO*WW*ER™ system were to assess the system's effectiveness in (1) removing organic and inorganic

contaminants from leachate; (2) producing a small volume of concentrated residual waste known as brine for further treatment or disposal; (3) producing a noncondensible gas stream that meets proposed permit requirements for the LCTC site, and (4) producing a condensate stream nontoxic to aquatic organisms. This section discusses technology testing and sampling procedures.

The technology demonstration was conducted under one set of operating parameters, which were established by CWM based on past operating experience with the PO*WW*ER™ system. Table B-l summarizes the system's operating parameters during the SITE demonstration. These operating parameters were applied in two sets of test runs: one set of three replicate test runs using unspiked LCTC landfill leachate and one set of three replicate test runs using LCTC landfill leachate spiked with the following compounds: 100 milligrams per liter (mg/L) each of methylene chloride, tetrachloroethene (PCE), and toluene; 10 mg/L of phenol; 2 mg/L cadmium; 0.2 mg/L mercury; and 50 mg/L each of copper, nickel, and iron. Table B-2 presents a summary of the operating temperatures and flow rates recorded during each SITE demonstration test run.

Table B-l. SITE Demonstration Test Conditions

Parameter	Value
Acid or caustic addition to feed	None
Antifoam agent addition to feed	Agent EP-530 as needed
Feed rate	0.16 t0 0.21 gallonsperminute (gpm)
Concentration ratio	31.4 to 32.3
Oxidizer inlet temperature	NA
Catalyst bed depth	NA
Scrubbing liquor	NA
Boiling point rise (BPR)	NA

Note:

NA — Information not available (see Section 3.8 for details).

Table B-2. Operating Temperatures and Flow Rates of the PO*WW*ER™ Pilot System During the SITE Demonstration

Run No.	Feed[a]		Product Condensate[b]		Brine[c]	Noncondensible Gas	
	Flow Rate (gpm)	Temperature °F	Flow Rate (gpm)	Temperature °F	Volume (Gallons)	Flow Rate[d] (scfm)	Temperature °F
Unspiked							
1	0.18	75	0.18	132	5.05	24.1	80
2	0.21	77	0.19	135	4.73	27.3	78
3	0.19	78	0.17	133	3.61	25.7	77
Spiked							
1	0.19	81	0.21	132	5.00	24.9	81
2	0.16	80	0.15	116	4.26	23.6	78
3	0.17	79	0.12	99	5.91	21.5	70
Average	0.18	78	0.17	125	4.76	24.52	77

Notes:

[a] The feed waste flow rate was estimated using the rate of level indicator changes. The rate of level indicator changes were converted to volumetric rate changes by using a calibration line established during the SITE demonstration. The volume of feed waste sampled and purged was subtracted from the volume fed into the PO*WW*ER™ pilot system. The feed waste temperatures reported represent an average of nine hourly independent measurements.

[b] The product condensate flow rate was estimated using the rate of level indicator changes. The rate of level indicator changes were converted to volumetric rate changes by using a calibration line established during the SITE demonstration. The product condensate was sampled after the product condensate tank; therefore, no volume corrections were required. The product condensate temperatures reported represent an average of nine hourly independent measurements.

[c] Brine was wasted and sampled only once during each 9-hour test period. Therefore, the reported values represent the total volume wasted and sampled during the 9-hour test period. Because of field difficulties, brine temperature was not measured during the SITE demonstration.

[d] scfm — standard cubic feet per minute

During the SITE demonstration, about 308 gallons of unspiked landfill leachate and 280 gallons of spiked landfill leachate were treated. Each demonstration test required about 9 hours of PO*WW*ER™ system operation to conduct sampling and monitoring operations.

Sampling began when the PO*WW*ER™ system operated under steady-state conditions. During the unspiked test runs, sampling began 9 days after the LCTC PO*WW*ER™ pilot plant started operating. For each set of test runs, sampling was conducted over a period of 3 days. During the spiked test runs, sampling began 48 hours after the spiked leachate feed waste was first introduced in the PO*WW*ER™ system. The target spiking solution concentrations were based on a feed waste volume of 500 gallons. The actual spiking solution concentrations of some VOCs were less than the target spiking solution concentrations probably because of VOC losses during mixing of feed waste with the spiking solution. During the 3-day sampling period, spiking compounds were added daily to the feed waste tank, which contained unspiked leachate, at least 1 hour before sampling began. This procedure allowed the leachate and the spiking compounds in the feed tank to mix for approximately 1 hour, ensuring thorough mixing of the leachate and preventing stratification

of the chemicals added. Spiking solutions were added to the feed tank daily. Spiking during the approximate 48-hour period preceding sampling allowed the concentrations of spiking compounds in the brine to reach approximately steady-state concentrations.

During each test run, samples were collected from the feed waste, product condensate, brine, and noncondensible gas stream. Feed waste, product condensate, and brine samples were analyzed for total suspended solids (TSS), total dissolved solids (TDS), ammonia, cyanide, volatile organic compounds (VOC), semivolatile organic compounds (SVOC), oil and grease, total organic halides (TOX), total organic carbon (TOC), metals, chloride, nitrate, sulfate, and pH. Samples of feed waste and product condensate were also analyzed for acute toxicity. Brine samples were also analyzed for toxicity characteristic leaching procedure (TCLP) metals, VOCs, and SVOCs. Continuous emissions monitoring (CEM) of the noncondensible gas stream included monitoring for total nonmethane hydrocarbons (TNMHC), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and oxygen. Noncondensible gas samples were also collected and analyzed for VOCs, SVOCs, and hydrochloric acid

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Critical analytes for the feed waste and product condensate included VOCs, SVOCs, ammonia, cyanide, TSS, TDS, and acute toxicity, which was a critical analyte only for the product condensate. Critical analytes for the brine were TSS and TDS. Critical analytes for the noncondensible gas stream were CO, NOx, and SO,.

For feed waste and product condensate, nine samples were collected for each critical analyte during each set of three replicate runs. For each critical analyte except VOCs and acute toxicity testing, one composite sample was collected every 3 hours, resulting in nine samples at the end of each set of three replicate runs. A sample was composited from equal portions of three successive grab samples collected every hour. VOC samples were collected as grab samples once every 3 hours in order to avoid losses during compositing. Acute toxicity testing samples were collected as grab samples once each day. Brine was wasted and sampled only once during each 9-hour test run. The noncondensible gas stream was monitored using a CEM system.

For feed waste and product condensate, three samples were collected for each noncritical analyte during each set of three replicate test runs, one 9-hour composite sample for each analyte. Feed waste and product condensate pH was measured in the field every 3 hours. Brine pH was measured in the laboratory.

During each set of three replicate runs for the noncondensible gas stream, nine samples were collected for VOCs using the Volatile Organic Sampling Train (VOST) sampling method; three samples were collected for SVOCs using the Modified Method 5 (MM5) sampling method, and three samples were collected for HCl using the Boilers and Industrial Furnaces (BIF) 0051 sampling method.

All sampling and analysis procedures met the requirements of a US. Environmental Protection Agency (EPA) Category II quality assurance project plan (QAPP) as specified in EPA's Risk Reduction Engineering Laboratory (RREL) document Preparation Aids for the Development of Category II Quality Assurance Project Plans, dated February 1991, Document No.EPA/600/8-91/004.

B.3 Treatment Results

This section summarizes analytical results of the PO*WW*ER™ system SITE demonstration and evaluates the system's effectiveness in treating landfill leachate contaminated with VOCs, SVOCs, ammonia, cyanide, metals and other inorganic contaminants and oil and grease. The following sections summarize: (1) results for critical parameters and (2) results for noncritical parameters.

B.3.1 *Summary of Results for Critical Parameters*

Critical parameters for the PO*WW*ER™ system SITE demonstration include (1) volume reduction, (2) VOC removal, (3) SVOC removal, (4) ammonia and cyanide removal, (5) noncondensible gas emissions, and (6) acute toxicity. These parameters are discussed below.

Volume Reduction

The PO*WW*ER™ system reduces the volume of an aqueous waste by evaporation and concentrates nonvolatile contaminants in the brine. During each 9-hour test run at the LCTC site, the PO*WW*ER™ system processed about 98 gallons of feed waste. Brine was wasted and sampled only once during the 9-hour test period. The total volume of brine wasted during each 9-hour test run was about 4.8 gallons, or about 5 percent of the feed waste volume. Figure B-l shows the volume of feed waste processed by the PO*WW*ER™ system and the volume of brine wasted during each unspiked and spiked test run.

The PO*WW*ER™ system's effectiveness for volume reduction was evaluated based on the concentration ratio, which is defined as the ratio of TS concentration in the brine over the TS concentration in the feed waste. The TS concentration is estimated as the sum of TSS and TDS. Tables B-3 and B-4 summarize TSS and TDS concentrations in feed waste, product condensate, and brine during the unspiked and spiked test runs, respectively. The results show that the brine TS concentration during the unspiked and spiked test runs remained almost the same. However, the TSS concentration in brine increased during the spiked test runs, probably because of the precipitation of metals used as spiking compounds. Figure B-2 shows the TS concentration in feed waste and brine during each unspiked and spiked test run. The TS concentration in the brine was significantly higher than that in the feed waste. The TS concentration in brine was primarily comprised of nonvolatile contaminants originally present in the feed waste. Therefore, the increase in TS concentration in the brine was caused by the volume reduction of the feed waste. Therefore, the TS concentration ratio is a reliable measure of feed waste volume reduction that occurs during treatment in the PO*WW*ER™ system.
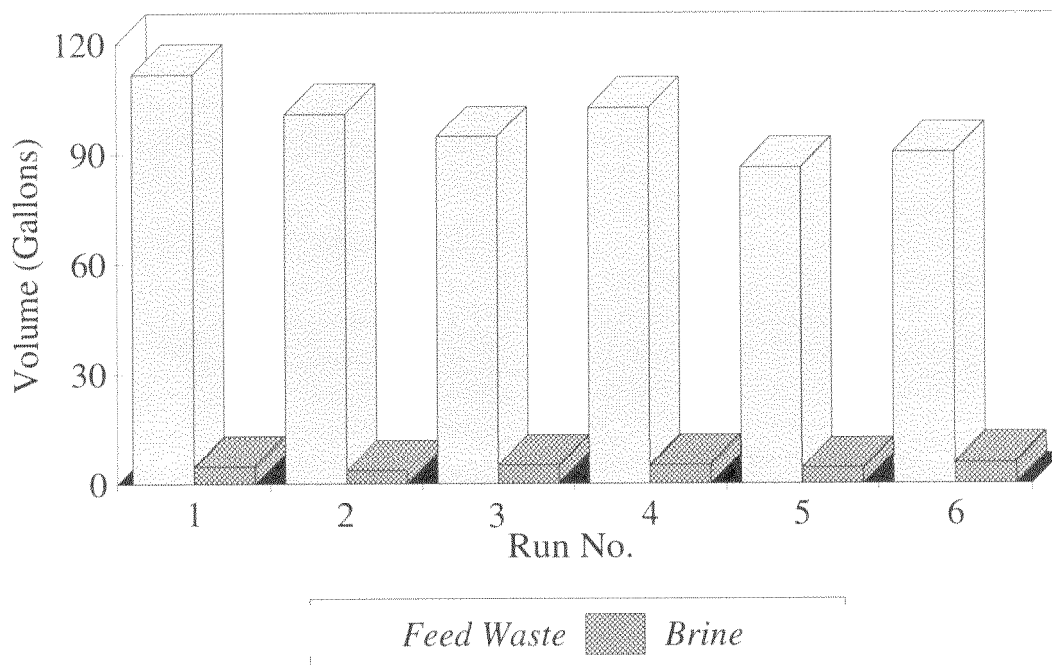
Figure B-1. Volume of feed waste and brine during the unspiked and spiked test runs

Note: Runs 1 through 3 were conducted with unspiked landfill leachate, and Runs 4 through 6 were conducted with spiked landfill leachate.

Table B-3. Summary of TSS, TDS, and TS Concentrations in Feed Waste, Product Condensate and Brine During Unspiked Test Runs

Run No.	Feed Waste TSS (mg/L)	Feed Waste TDS (mg/L)	Feed Waste TS[b] (mg/L)	Product Condensate TSS (mg/L)	Product Condensate TDS (mg/L)	Product Condensate TS[b] (mg/L)	Brine[a] TSS (mg/L)	Brine[a] TDS (mg/L)	Brine[a] TS[b] (mg/L)
1	80 H[c]	16,000 H	16,000	<4 H[d]	<10 H	<14			
	100 H	16,000 H	16,000	<4 HB[e]	<10 H	<14	700 H	530,000 H	530,000
	80 H	17,000 H	17,000	<4 H	<10 H	<14			
Average	87	16,000	16,000	<4	<10	<14	NA[f]	NA	NA
2	180	16,000	16,000	<4	<10	<14			
	150	16,000	16,000	<4	<10	<14	1,900	500,000	500,000
	180	16,000	16,000	<4	<10	<14			
Average	170	16,000	16,000	<4	<10	<14	NA	NA	NA
3	140	17,000	17,000	<4	<10 B	<14			
	90	17,000	17,000	<4	<10 B	<14	550	530,000	530,000
	120	17,000	17,000	<4	<10 B	<14			
Average	120	17,000	17,000	<4	<10	<14	NA	NA	NA

Notes:
[a] Brine was wasted and sampled once per test run. Therefore, the reported results represent analysis of one sample. However, during the second run of the unspiked tests, three replicate samples were collected and analyzed, and the results shown represent the average of the three replicate samples.
[b] This value represents the sum of the respective TSS and TDS values.
[c] H indicates that the analyte concentration is estimated because holding time was exceeded.
[d] < = Not detected at detection limit shown
[e] B indicates that the analyte was not detected at a concentration greater than ten times the concentration found in an associated blank.
[f] NA = Not applicable

Table B-4. Summary of TSS, TDS, and TS Concentrations in Feed Waste, Product Condensate and Brine During Spiked Test Runs

Run No.	Feed Waste TSS (mg/L)	Feed Waste TDS (mg/L)	Feed Waste TS[b] (mg/L)	Product Condensate TSS (mg/L)	Product Condensate TDS (mg/L)	Product Condensate TS[b] (mg/L)	Brine[a] TSS (mg/L)	Brine[a] TDS (mg/L)	Brine[a] TS[b] (mg/L)
	750	16,000	17,000	<4[c]	<10	<14			
1	500	15,000	16,000	<4	<10	<14	4,800	560,000	560,000
	400	16,000	16,000	<4	<10	<14			
Average	550	16,000	16,000	<4	<10	<14	NA[d]	NA	NA
	700	17,000	18,000	<4	<10	<14			
2	600	16,000	17,000	<4	<10	<14	5,500	540,000	550,000
	600	16,000	17,000	<4	<10	<14			
Average	630	16,000	17,000	<4	<10	<14	NA	NA	NA
	350	16,000	16,000	<4	<10	<14			
3	400	17,000	17,000	<4	<10	<14	7,500	500,000	510,000
	400	17,000	17,000	<4	16	<20			
Average	380	17,000	17,000	<4	<12[e]	<16	NA	NA	NA

Notes:
[a] Brine was wasted and sampled once per test run. Therefore, the reported results represent analysis of one sample.
[b] This value represents the sum of the respective TSS and TDS values.
[c] < = Not detected at detection limit shown
[d] NA = Not applicable
[e] This value represents the average of concentrations measured above and below the detection limit.
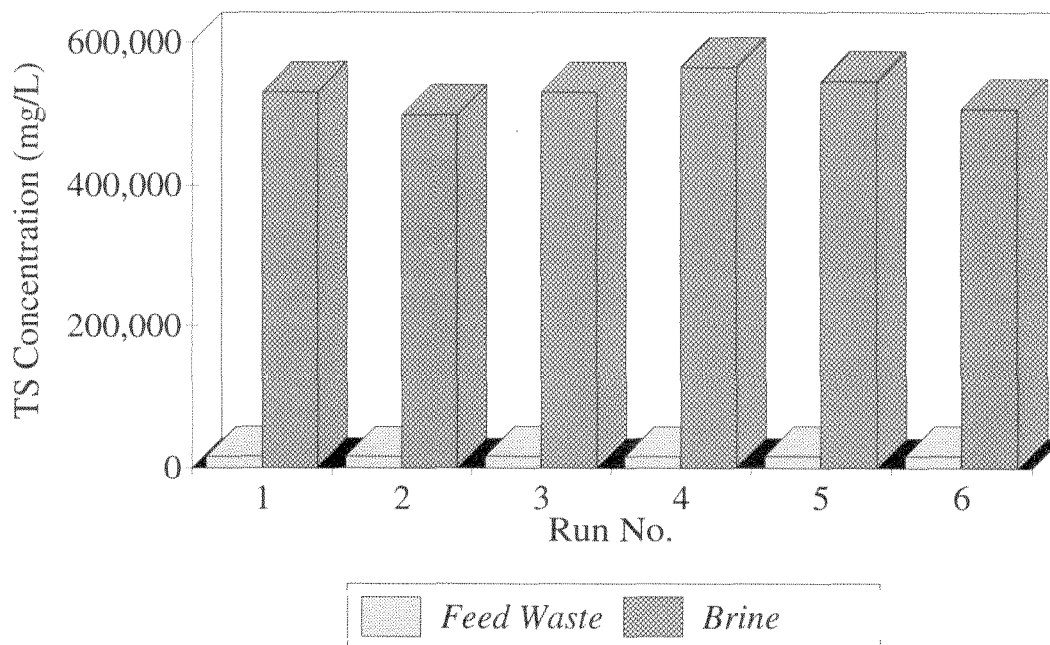
Note: Runs 1 through 3 were conducted with unspiked landfill leachate, and Runs 4 through 6 were conducted with spiked landfill leachate.

Figure B-2. TS concentration of feed waste and brine during the unspiked and spiked test runs

The concentration ratio of chloride and metals in the brine and feed waste was also estimated. Table B-5 summarizes the concentration ratios estimated based on TS, chloride, and metals. The concentration ratio based on TS was estimated to be about 3 1 to 1 and 32 to 1 during the unspiked and spiked test runs, respectively. The chloride concentration ratio was 33 to 1 and 31 to 1 during the unspiked and spiked test runs, respectively. The metals concentration ratio was 33 to 1 and 30 to 1, respectively. **The** results show that TS, chloride, and metals concentration ratios are almost identical. A statistical test was conducted using the Student's t-test distribution to compare the average concentration ratios of TS, chloride, and metals (Kleinbaum and Kupper, 1978). The statistical test shows that with 99 percent confidence, the average ratios are not significantly different. Therefore, the estimate of the concentration ratio is reliable and is considered to represent **a** reliable measure of feed waste volume reduction achieved during treatment in the **PO*WW*ER™** system. The concentration ratios achieved during the unspiked test runs are very similar to those achieved during the spiked test runs. This similarity is expected because during the spiked test runs, the spiking compounds added in relatively large amounts were VOCs, which evaporate and do not contribute to TS concentration in the brine.

Table B-5. Concentration Ratios During Unspiked and Spiked Test Runs

Unspiked Test Runs			
Run No.	TS	Chloride	Metals
1	32	32	31
2	31	35	35
3	31	32	34
Average	31	33	33
Standard Deviation	0.65	1.6	1.8

Spiked Test Runs			
Run No.	TS	Chloride	Metals
1	35	33	30
2	32	28	29
3	30	33	31
Average	32	31	30
Standard Deviation	2.1	2.0	1.0

VOC Removal

Acetone, 2-butanone, methylene chloride, PCE, toluene, and vinyl chloride were identified as critical VOCs for the PO*WW*ER™ system SITE demonstration. During the spiked test runs, feed waste was spiked with 100 mg/L of each of the following: methylene chloride, PCE, and toluene. The purpose of spiking the feed waste was to test the effect of contaminant loading on VOC treatment efficiency.

Vinyl chloride was not detected during unspiked and spiked test runs in feed waste, product condensate, or brine. The detection limit for the feed waste was 1,000 micrograms per liter (μg/L) during the unspiked test runs and ranged from 5,000 to 10,000 μg/L; for the brine it was less than 100 μg/L during both the unspiked and spiked test runs. Therefore, vinyl chloride is not discussed further. Table B-6 summarizes analytical results of critical VOCs during the unspiked and spiked test runs.

During the unspiked test runs, acetone concentration in feed waste samples ranged from 8,200 to 12,000 ug/L; in brine samples it was less than the detection limit of 100 μg/L during the first and second unspiked test runs and 140 μg/L during the third unspiked test run; and in product condensate samples it was less than the detection limit of 10 μg/L. During the spiked test runs, acetone concentration in feed waste samples ranged from 13,000 to 18,000 ug/L; in brine samples, it ranged from 180 to 220 μg/L. The results indicate that during the spiked test runs, acetone was not completely removed from the brine. Because acetone was not one of the spiking compounds, the results suggest that total contaminant loading, which increased during the spiked test runs, had a measurable effect on the acetone evaporation efficiency. However, the concentration of acetone in product condensate was less than the detection limit of 10 μg/L, indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, 2-butanone concentration in feed waste samples ranged from 1,500 to 2,200 μg/L; in brine samples it was less than the detection limit of 100 μg/L; and in product condensate samples it was less than the detection limit of 10 ug/L. During the spiked test runs, 2-butanone concentration in feed waste samples was less than 10,000 μg/L; in brine samples it was less than the detection limit of 100 μg/L; and in product condensate samples it was less than the detection limit of 10 ug/L. These results indicate that total contaminant loading had no measurable effect on 2-butanone evaporation efficiency or product condensate quality.

During the unspiked test runs, methylene chloride concentration in feed waste samples ranged from 640 to 1,700 ug/L; in brine samples it was less than the detection limit of 50 ug/L; in product condensate samples it was less than the detection limit of 5 μg/L during the first and third unspiked tests. However, during the second unspiked test run, methylene chloride concentration ranged from 5 to 8 μg/L. During the spiked test runs, methylene chloride

Table B-6. Critical VOC Concentrations During Unspiked and Spiked Test Runs

Run No.	Unspiked Test Runs			Spiked Test Runs		
	Feed Waste	Product Condensate	Brine[a]	Feed Waste	Product Condensate	Brine[a]
			Acetone (µg/L)			
	11000 M [b]	<10[c]		13000 M	<10 M	
1	11000 M	<10	<100	13000 M	<10 M	220 M
	12000 M	<10		13000 M	<10 M	
Average	11000 M	<10	NA[f]	13000 M	<10 M	NA
	8300 M	4 (10)[d]		14000 M	<10 M	
2	8800 M	<10	<100	13000 M	<10 M	180 M
	9100 M	5 (10)		13000 M	<10 M	
Average	8700 M	<6[g]	NA	13000 M	<10 M	NA
	8200 M	<10		17000 M	<10 M	
3	9300 M	<10	140	18000 M	<10 M	180 M
	9700 M	<10		15000 M	<10 M	
Average	9100 M	<10	NA	17000 M	<10 M	NA
			2-Butanone (µg/L)			
	1800	<10		<10000	<10	
1	2200	<10	<100	<10000	<10	< 100 M
	2200	<10		<10000	<10	
Average	2100	<10	NA	<10000	<10	NA
	1500	<10		2900 (5000)	<10	
2	1500	<10	<100	2700 (5000)	<10	< 100 M
	1500	<10		<5000	<10	
Average	1500	<10	NA	<3500[g]	<10	NA
	1600	<10		<10000	<10	
3	1800	<10	<100	<10000	<10	< 100 M
	1900	<10		3100 (5000)	<10	
Average	1800	<10	NA	<7700[g]	<10	NA
			Methylene Chloride (µg/L)			
	1300	<5		110000 C	<5	
1	1100	<5 C[e]	<50	110000 C	<5	190
	890	<5		100000 C	<5	
Average	1100	<5	NA	110000 C	<5	NA
	1700	8		93000 C	<5 C	
2	1100	6	<50	93000 C	<5	110
	640	5 C		88000 C	<5	
Average	1100	6	NA	91000 C	<5	NA
	710	<5		95000 C	<5 C	
3	640	<5 C	< 50	100000 C	<5	200 C
	730	<5		96000 C	<5	
Average	690	<5	NA	97000 C	<5	NA
			PCE (µg/L)			
	<500	<5		50000 M	<5	
1	170 (500)	<5	<50	54000 M	<5	69 M
	<500	<5		55000 M	<5	
Average	<390[g]	<5	NA	53000 M	<5	NA
	<500	<5		47000 M	<5	
2	<500	<5	<50	47000 M	<5	46 (50)M
	<500	<5		52000 M	<5	
Average	<500	<5	NA	49000 M	<5	NA

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Run No.	Unspiked Test Runs			Spiked Test Runs		
	Feed Waste	Product Condensate	Brine[a]	Feed Waste	Product Condensate	Brine[a]
	<500	<5		55000 M	<5	
3	<500	<5	<50	60000 M	<5	34 (50)M
	<500	<5		49000 M	<5	
Average	<500	<5	NA	55000 M	<5	NA
			Toluene (µg/L)			
	370 (500)	1 (5)		68000	<5	
1	420 (500)	<5	<50	69000	<5	49 (50)
	370 (500)	1 (5)		62000	<5	
Average	390 (500)	<2[g]	NA	66000	<5	NA
	370 (500)	<5		55000	<5	
2	350 (500)	<5	<50	50000	<5	49 (50)
	320 (500)	<5		52000	<5	
Average	350 (500)	<5	NA	52000	<5	NA
	410 (500)	<5		55000	<5	
3	440 (500)	<5	<50	57000	<5	37(50)
	350 (500)	<5		46000	<5	
Average	400 (500)	<5	NA	53000	<5	NA

Notes:
[a] Brine was wasted and sampled once per test run. Therefore, the reported results represent analysis of one sample.
[b] M indicates that the analytes concentration is estimated because MS/MSD precision or accuracy criteria were not met.
[c] < = Analyte not detected at the detection limit shown
[d] Analyte detected at an estimated concentration below the detection limit shown in parentheses
[e] C indicates that analyte concentration is estimated because calibration criteria were not met.
[f] NA = Not applicable
[g] This value represents the average of concentrations estimated below the detection limit and at the detection limit, as well.

concentrations in feed waste samples ranged from 88,000 to 110,000 µg/L, and in brine samples it ranged from 110 to 200 µg/L. The results suggest that contaminant loading, which increased during the spiked test runs, had a slight but measurable effect on methylene chloride evaporation efficiency. However, methylene chloride concentration in product condensate was less than the detection limit of 5 µg/L, indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, PCE concentration in feed waste samples were less than the detection limit of 500 µg/L; in brine samples it was less than the detection limit of 50 µg/L; and in product condensate samples it was less than the detection limit of 5 µg/L. During the spiked test runs, PCE concentration in feed waste samples ranged from 47,000 to 60,000 µg/L, and in brine samples it ranged from less than the detection limit of 50 to 69 µg/L. The results suggest that contaminant loading, which increased during the spiked test runs, had a slight but measurable effect on PCE evaporation efficiency. However, the concentration of PCE in product condensate was less than the detection limit of 5 µg/L, indicating that total contaminant loading had no measurable effect on product condensate quality.

During the unspiked test runs, toluene concentration in feed waste samples was less than the detection limit of 500 µg/L; in brine samples it was less than the detection limit of 50 µg/L; and in product condensate samples it was less than the detection limit of 5 µg/L. During the spiked test runs, toluene concentration in feed waste samples ranged from 46,OOO to 69,000µg/L; in brine samples it was less than the detection limit of 50 µg/L; and in product condensate samples it was less than the detection limit of 5 µg/L. The results suggest that contaminant loading had no measurable effect on toluene evaporation efficiency or product condensate quality.

SVOC Removal

Benzoic acid and phenol were identified as critical SVOCs for the PO*WW*ER™ system SITE demonstration. During the spiked tests feed waste was spiked with 10 mg/L of phenol to test the effect of contaminant loading on the SVOC treatment efficiency. Table B-7 summarizes analytical results of critical SVOCs during unspiked and spiked test runs.

During the unspiked test runs, benzoic acid concentration in feed waste samples ranged from 6,300 to 24,000 ug/L; in brine samples it ranged from 600,000 to 1,600, 000 ug/L; in product condensate samples it was less

than the detection limit, which ranged from 25 to 130 µg/L. During the spiked test runs, the benzoic acid concentration in feed waste samples ranged from 13,000 to 24,000 ug/L; in brine samples it ranged from 620,000 to 930,000 ug/L; and in product condensate samples it was less than the detection limit, which was 130 µg/L for most samples analyzed. The results indicate that during the unspiked and spiked test runs, benzoic acid remained primarily in the brine.

During the unspiked test runs, phenol concentration in feed waste samples ranged from 5,300 to 11,000 µg/L; in brine samples it was less than the detection limit of

Table B-7. Critical SVOC Concentrations During Unspiked and Spiked Test Runs

Run No.	Unspiked Test Runs			Spiked Test Runs		
	Feed Waste	Product Condensate	Brine[a]	Feed Waste	Product Condensate	Brine[a]
	Benzoic Acid (µg/L)					
	17000 M[b]	<25[c]		24000	<130	
1	15000 M	<25	600000 H[d]	23000	<130	620000 H
	15000 M	<25		21000	<130	
Average	16000 M	<25	NA[e]	23000	<130	NA
	16000 M	<130		13000	<130	
2	18000 M	<130	690000	13000	<130	800000 H
	16000 M	<130		15000	<25	
Average	17000 M	<130	NA	14000	<95[f]	NA
	6300 M	<25		20000	<130	
	24000 M	<25	1600000	15000	<25	930000 H
	7100 M	<25		16000	<130	
Average	12000 M	<25	NA	17000	<95[f]	NA
	Phenol (µg/L)					
	8900 M	<10		17000 M	<50	
	8800 M	<10	<200000 H	17000 M	<50	<200000 H
	9600 M	<10		17000 M	<50	
Average	9100 M	<10	NA	17000 M	<50	NA
	8100 M	<50		14000 M	<50	
2	11000 M	<50	<200000	13000 M	<50	<200000 H
	11000 M	<50		12000 M	<10	
Average	10000 M	<50	NA	13000 M	<37[f]	NA
	5300 M	<10		12000 M	<50	
3	7300 M	<10	<200000	13000 M	<10	<200000 H
	5300 M	<10		14000 M	<50	
Average	6000 M	<10	NA	13000 M	<37[f]	NA

Notes:
[a] Brine was wasted and sampled once per test run. Therefore, the reported results represent analysis of one sample
[b] M indicates analyte concentration was estimated because MS/MSD accuracy or precision criteria were not met.
[c] < = Analyte not detected at detection limit shown
[d] H indicates that analyte concentration is estimated because holding time was exceeded.
[e] NA = Not applicable
[f] This value represents the average of three detection limits, where at least one limit differs from the other two.

200,000 ug/L; in product condensate samples it was less than the detection limit, which ranged from 10 to 50 ug/L. During the spiked test runs, the phenol concentration in feed waste samples ranged from 12,000 to 17,000 ug/L; in brine samples it was less than the detection limit of 200,000 ug/L; and in product condensate samples it was less than the detection limit of 50 ug/L. The results suggest that phenol vaporizes, at least partially, and is presumably oxidized in the catalytic oxidizer. Although.benzoic acid and phenol are both acidic compounds, they have very different physical-chemical properties. Given these properties, phenol is more likely than benzoic acid to be removed from the brine. Phenol has a vapor pressure over 30 times greater than benzoic acid. Also, under the test conditions, phenol was likely present in the brine primarily in unionized form while benzoic acid was likely present in ionized form.

Phenol has a boiling point of 358 "F, which is significantly higher than the steam temperature used for heating in the evaporator heat exchanger. However, the evaporation of semivolatile contaminants in the evaporator can take place because of the increase in boiling point, known as the BPR, the stripping effect of steam, and the solution ionic strength. The BPR is the difference between the boiling point of a solution and the boiling point of water at the same pressure. The BPR occurs because of increased concentration of solids in the evaporator. During the SITE demonstration, the BPR was not recorded because of testing limitations imposed by CWM.

Another reason that could have caused the evaporation of phenol is the effect of ionic strength. Because the concentration of ionic species increases in the brine because of the evaporation of water, ionic strength also increases. High ionic strength results in a decrease in the solubility of molecular species such as phenol. This phenomenon is known as the "salting-out effect" and may cause the evaporation of some SVOCs.

Ammonia and Cyanide Removal

Ammonia and cyanide were identified as critical inorganic contaminants during the SITE demonstration. The evaporation efficiency of ammonia and cyanide in the PO*WW*ER™ system depends on feed waste pH and the types of metals present. Under certain conditions, the PO*WW*ER™ system vaporizes ammonia and cyanide in the evaporator and oxidizes both in the catalytic oxidizer. **Ammonia forms** complexes with cadmium, cobalt, copper, silver, mercury, nickel, and zinc. Cyanide forms complexes

with cadmium, copper, silver, mercury, iron, nickel, and zinc. All the above-mentioned metals were present in feed waste samples during unspiked and spiked test runs. Metal complexes of ammonia and cyanide need to be destroyed before ammonia and cyanide can be evaporated and oxidized. Free ammonia volatilizes effectively at pH values greater than 9. Free cyanide volatilizes effectively at pH values less than 9. Table B-8 summarizes analytical results of ammonia and cyanide during unspiked and spiked test runs.

During the unspiked test runs, ammonia concentration in feed waste samples ranged from 150 to 160 mg/L; in brine samples it ranged from 5.4 to 23 mg/L; and in product condensate samples it was less than the detection limit of 0.1 mg/L. During the spiked test runs, ammonia concentration in feed waste samples ranged from 140 to 160 mg/L; in brine samples it ranged from 7.4 to 7.8 mg/L; and in product condensate samples it was less than the detection limit of 0.1 mg/L. The results indicate that during the unspiked and spiked test runs, ammonia was not completely removed from the brine, possibly because the feed waste pH ranged from 8.5 to 9.1, close to the lower optimum pH range for ammonia volatilization, or because ammonia complexed with metals, which were present in the feed waste.

During the unspiked test runs, cyanide concentration in feed waste samples ranged from 25 to 34 mg/L; in brine samples it ranged from 77 to 150 mg/L; and in product condensate samples it was less than the detection limit of 0.01 mg/L. During the spiked test runs, cyanide concentration in the feed waste ranged from 24 to 36 mg/L; in brine samples it ranged from 17 to 77 mg/L; and in product condensate samples it was less than the detection limit of 0.01 mg/L. The results indicate that during the spiked test runs, cyanide was not completely removed from the brine, possibly because the feed waste pH ranged from 8.5 to 9.1, which is near the upper optimum pH range for cyanide volatilization, or because cyanide complexed with metals, which were present in the feed waste.

Figure B-3 shows evaporation efficiencies of ammonia and cyanide during the unspiked and spiked test runs. The percent (%) evaporation efficiency is defined by the following equation:

$$\% \text{ Evap. Eff.} = \frac{W_{feedwaste} - W_{brine}}{W_{feedwaste}} \times 100 \qquad (B-1)$$

Table B-8. Critical Inorganic Contaminants During Unspiked and Spiked Test Runs

Run No.	Unspiked Test Runs			Spiked Test Runs		
	Feed Waste	Product Condensate	Brine[a]	Feed Waste	Product Condensate	Brine[a]
			NH_3(mg/L)			
	150	<0.10[b]		160 H	<0.10 H	
1	150	<0.10	5.4	150 H	<0.10 H	7.8 H[c]
	160	<0.10		160 H	<0.10 H	
Average	150	<0.10	NA[d]	160 H	<0.10 H	NA
	150	<0.10		140 H	<0.10 H	
2	150	<0.10	23 H	150 H	<0.10 H	7.5 H
	150	<0.10		150 H	<0.10 H	
Average	150	<0.10	NA	150 H	<0.10 H	NA
	160	<0.10		140	<0.10	
3	160	<0.10	11	140	<0.10	7.4
	150	<0.10		140	<0.10	
Average	160	<0.10	NA	140	<0.10	NA
			CN^-(mg/L)			
	32	<0.01		30	<0.01	
1	31	<0.01	77	36	<0.01	36
	25	<0.01		33	<0.01	
Average	29	<0.01	NA	33	<0.01	NA
	32	<0.01		32	<0.01	
2	34	<0.01	150	31	<0.01	17
	34	<0.01		33	<0.01	
Average	33	<0.01	NA	32	<0.01	NA
	29	<0.01		24	<0.01	
3	31	<0.01	140	24	<0.01	77
	31	<0.01		24	<0.01	
Average	30	<0.01	NA	24	<0.01	NA

Notes:
[a]   Brine was wasted and sampled once per test run. Therefore, the reported results represent analysis of one sample.
[b]   < = Analyte not detected at detection limit shown
[c]   H indicates that analyte concentration was estimated because holding time was exceeded.
[d]   NA = Not applicable

where

$W_{feed\ waste}$ =   mass of ammonia or cyanide in feed waste

W_{brine} =   mass of ammonia or **cyanide** in brine

The ammonia evaporation efficiencies ranged from 99.4 to 99.8 percent during the unspiked test runs and from 99.7 to 99.8 percent during the spiked test runs. The cyanide evaporation efficiencies ranged from 81 .O to 86.0 percent during the unspiked test runs and from 79.1 to 97.4 percent during the spiked test runs. Apparently, ammonia showed a higher evaporation efficiency because the pH of the feed waste, which ranged from 8.5 to 9.1, and the pH of brine,

which was **greater** than 10, encourage **ammonia** evaporation. Cyanide evaporation is more effective in the acidic pH range. Another reason that may have contributed to the lower cyanide evaporation efficiency is its tendency to form much stronger complexes with metals, particularly iron. These complexes are very hard to destroy in order to release the cyanide. Some metal cyanide complex destruction can be achieved under acidic conditions, but iron-cyanide complexes are hard to destroy even under acidic conditions (Butler, 1964). During the SITE demonstration, the pH of the brine was greater than 10, which is advantageous to the volatilization of ammoniabut not cyanide.
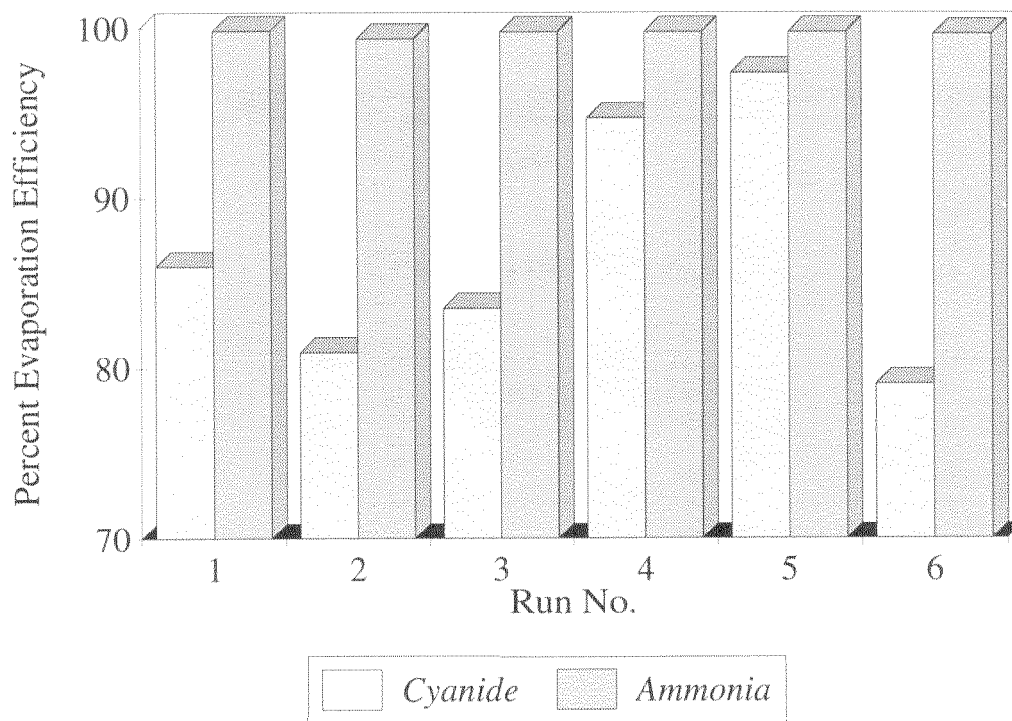
Note: Runs 1 through 3 were conducted with unspiked landfill leachate, and Runs 4 through 6 were conducted with spiked landfill leachate.

Figure B-3. Cyanide and ammonia evaporation efficiencies during unspiked and spiked test runs.

Noncondensible Gas Emissions

During the SITE demonstration, CEM of the noncondensible vent gas was conducted. Table B-9 summarizes the CEM results. The CO, SO_2, and NO_x concentrations are discussed below. The average CO concentrations ranged from 9.58 to 37.3 parts per million by volume (ppmv), resulting in emissions ranging from 1.1×10^{-3} to 3.92×10^{-3} pounds per hour(lb/hr); the 60-minute maximum CO concentrations ranged from 11.1 to 40.8 ppmv, resulting in emissions ranging from 1.27×10^{-3} to 4.28×10^{-3} lb/hr. The average SO_2 concentrations were less than 2 ppmv, resulting in emissions of less than 5.5×10^{-4} lb/hr. The 60-minute maximum SO_2 concentrations ranged from less than 2 to 3.49 ppmv, resulting in emissions ranging from less than 5.5×10^{-4} to 8.4×10^{-4} lb/hr. The average NO_x concentrations ranged from 233 to 292 ppmv, resulting in emissions ranging from 3.46×10^{-2} to 5.03×10^{-2} 'lb/hr. The 60-minute maximum NO_x concentrations ranged from 241 to 309 ppmv, resulting in emissions ranging from 3.59×10^{-2} to 5.34×10^{-2} lb/hr. The noncondensible vent gas emissions for these parameters met the proposed regulatory requirements for the LCTC site.

During the SITE demonstration, noncondensible vent gas samples were collected and analyzed for VOCs, SVOCs, and HCl. The following VOCs were detected at trace levels: chloromethane; bromomethane; methylene chloride; acetone; carbon disulfide; 2-butanone; 1,1,1-trichloroethane; benzene; PCE; toluene; chlorobenzene; and ethylbenzene. Acetone, 2-butanone, methylene chloride, PCE, and toluene are critical analytes consistently present in the feed waste. The critical VOC present at the highest concentration in the noncondensible vent gas was PCE. During the first and third unspiked test runs, the concentration of PCE was less than the detection limits of 2.47 and 2.44 ppmv, respectively. During the second unspiked run, PCE was present at 3.93 ppmv. During the spiked test runs, the concentration of PCE ranged from 173 to 285 ppmv. The highest PCE concentration occurred during the first spiked test run, which had the highest NO_x, SO_2, CO, and TNMHC concentrations. All other VOCs were present at concentrations less than 50 micrograms per dry standard cubic meter (ug/dscm) and usually below 10 ug/dscm.

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Table B-9. Noncondensible Gas Average and Maximum Concentrations and Mass Emissions Rates

Contaminant	Unspiked Test Runs			Spiked Test Runs		
	1	2	3	1	2	3
Average[a] CO (ppmv)	21.4	9.58	13.9	37.3	24.6	18.7
Average CO (lb/hr)	0.00217	0.00110	0.00151	0.00392	0.00244	0.00169
60-minute RA[b] Maximum CO (ppmv)	22.5	11.1	15.4	40.8	26.5	19.8
60-minute RA Maximum CO (lb/hr)	0.00228	0.00127	0.00166	0.00428	0.00263	0.00179
Average SO_2 (ppmv)	[c]<2	<2	<2	<2	<2	<2
Average SO_2 (lb/hr)	<0.00049	<0.00055	<0.00052	<0.00051	<0.00048	<0.00043
60-minute RA Maximum SO_2 (ppmv)	2.40	<2	<2	3.49	2.87	<2
60-minute RA Maximum SO_2 (lb/hr)	0.00056	<0.00055	<0.00052	0.00084	0.00065	<0.00043
Average NO_x[d] (ppmv)	242	260	243	292	255	233
Average NO_x[d] (lb/hr)	0.0404	0.0491	0.0432	0.0503	0.0417	0.0346
60-minute RA Maximum NO_x[d] (ppmv)	253	275	254	309	280	241
60-minute RA Maximum NO_x[d] (lb/hr)	0.0421	0.0519	0.0452	0.0534	0.0458	0.0359
Average TNMHC (ppmv)	<2	<2	<2	<2	<2	<2
Average TNMHC (lb/hr)	<0.00033	<0.00037	<0.00035	<0.00037	<0.00032	<0.00029
60-minute RA Maximum TNMHC (ppmv)	<2	<2	<2	3.95	3.54	2.53
60-minute RA Maximum TNMHC (lb/hr)	<0.00033	<0.00037	<0.00035	0.00067	0.00057	0.00038

Notes:

[a] Average pollutant concentrations are calculated as the time-weighted average of each sampling period.

[b] Maximum pollutant concentrations are calculated as the maximum 60-minute rolling average (RA) concentration observed during each sampling period.

[c] < = Analyte not detected at the detection limit shown.

[d] As a corrective action, a conservative correction factor of about 10 percent increase was applied to all NO_x CEM readings.

HCl and some SVOCs were also detected. HCl was detected only during the second and third unspiked test runs. During the second unspiked test run, the concentration of HCl was 48.5 ug/dscm. The HCl concentration during the third unspiked test run was 247 ug/dscm.

The following SVOCs were also present in the noncondensible gas emissions at trace levels: phenol, benzoic acid, naphthalene, bis-(Zethylhexyl) phthalate, and di-n-octylphthalate. During the unspiked test runs, SVOCs were present in the noncondensible gas emissions at the following concentrations: phenol from less than 1.4 to 1.6 ug/dscm, benzoic acid from less than 6.8 to 6.8 ug/dscm, bis-(2-ethylhexyl) phthalate at less than 1.4 ug/dscm, and di-n-octylphthalate from less than 1.4 to 3.9 ug/dscm. During the spiked test runs, phenol concentrations ranged from less than 1.3 to 1.7 ug/dscm; benzoic acid concentrations ranged from less than 6.7 to 3 1.8 ug/dscm, bis-(Zethylhexyl) phthalate concentrations ranged from less than 1.3 to 31.4 ug/dscm, and di-n-octylphthalate concentrations ranged from less than 1.4 to 9 ugldscm.

During the SITE demonstration, the TNMHC concentration was also monitored by the CEM system. During the unspiked test runs, the average and maximum TNMHC concentration was less than the detection limit of 2 ppmv, resulting in emissions of less than 3.7×10^{-4} lb/hr. During the spiked test runs the average THMHC concentration was also less than the detection limit of 2 ppmv, resulting in emissions of less than 3.7×10^{-4} lb/hr. However, during the spiked test runs, the maximum TNMHC concentration ranged from 2.53 to 3.95 ppmv, resulting in emissions ranging from 3.8×10^{-4} to 6.7×10^{-4} lb/hr.

The SITE demonstration noncondensible gas emissions results indicate that increased contaminant loading during the spiked test runs results in relatively small increases in contaminant concentrations in the noncondensible vent gas.

Toxicity Test Results

The acute toxicity of leachate feed waste and product condensate was measured during each of the six test runs by conducting forty-eight-hour, static nonrenewal acute toxicity tests. Acute toxicity tests were conducted using

Ceriodaphnia dubia (C. dubia) and Pimephales promelas (P. promelas) as fresh water organisms and Mysidopsis bahia (M. bahia) and Cyprinodon variegatus (C. variegatus) as marine organisms.

Acute toxicity was measured under two sets of operationally-defined test conditions. Condition 1 was conducted using both marine and fresh water organisms. Condition 1 involved sample adjustments of hardness, temperature, pH, dissolved oxygen (DO) levels; for the marine organisms, salinity was adjusted. The objective of Condition 1 was to determine whether sources of acute toxicity are removed by the PO*WW*ER™ system. Feed waste and product condensate were both tested under Condition 1.

Condition 2 was conducted with fresh water organisms only and it involved the same adjustments made for Condition 1, except for hardness. Only product condensate was tested under Condition 2 to examine the acute toxicity of product condensate.

Tables B-10 and B-l 1 summarize median lethal concentration (LC50) values for feed waste and product condensate determined under Condition 1 for the species C. dubia, P. promelas, M. bahia, and C. variegatus. The results in Table B-10 show that feed waste was highly toxic, with LC50 values consistently less than 10 percent. LC50 values were lowest for C. dubia and highest for C. variegatus, suggesting that C. dubia was most affected and C. variegatus least affected by leachate feed.

The results in Table B-10 show that LC50 values were similar regardless of whether feed waste was unspiked or spiked. No measurable difference in acute toxicity of leachate feed was observed, although spiked leachate feed contained a higher total concentration of toxicants compared to the unspiked leachate feed. Since more concentrated solutions generally have a higher potential for toxicity (EPA, 1991b), sample characteristics and test conditions were observed to explain why spiking did not result in a measurable increase in leachate feed acute toxicity. Compounds added during spiking included primarily metals and VOCs. Metals added during spiking were probably precipitated as insoluble metal salts as indicated by the TSS results.

The average TSS concentration of spiked leachate feed was 527 mg/L, nearly four times more than the average TSS concentration of unspiked leachate feed. Metal

precipitation probably caused the higher TSS in spiked leachate feed. Precipitated or chelated metals and adsorbed metals or organic compounds are not as bioavailable as dissolved or free metals and organic compounds (EPA, 1991 b). Toxicity is related to the bioavailability of toxicants, and spiked leachate feed may have attenuated toxicity by removing bioavailable toxicants from solution by adsorption or precipitation.

Table B-10. Acute Toxicity of Feed Waste Measured as Percent LC50 Under Condition 1

		Organism		
Run No.	C. dubia	P. promelas	M. bahia	C. variegatus
		Unspiked Test Runs		
1	<1.5[a]	3.6	2.8	7.9
2	2.2	3.4	2.2	8.8
3	<1.5	<1.5	2.9	7.7
		Spiked Test Runs		
1	<1.5	3.0	2.6	5.8
2	2.0	2.2	2.6	8.8
3	<1.5	3.7	2.9	8.2

Note:
[a] < = Less than

Table B-11. Acute Toxicity of Product Condensate after Hardness Adjustment - Condition 1

		Organism		
Run No.	C.dubia	P. promelas	M. bahia	C. variegatus
		Unspiked Test Runs		
1	Nontoxic[c]	Nontoxic	>100[d]	>100
2	>100	>100	>100	>100
3	Nontoxic	Nontoxic	>100	>100
		Spiked Test Runs		
1	Nontoxic	Nontoxic	>100	>100
2	>100	>100	>100	>100
3	Nontoxic	Nontoxic	>100	>100

Notes:
[a] Hardness was adjusted to 80 to 100 mg/L as calcium carbonate
[b] Hardness exceeded 100 mg/L due to salinity adjustment.
[c] Screening test results; nontoxic means no toxicity in 100 percent product condensate
[d] Definitive test results; >100 = LC50 greater than 100 percent

All leachate feed samples were aerated during Condition 1 as required by the analytical method to prevent organism stress from low DO, thus preventing artifactual toxicity. However, aeration can strip VOCs from the solution and possibly affect toxicity test results (EPA, 1991b). Aeration was within the range constraints of the acute toxicity test

during testing, and it is not known whether aeration removed toxicants sufficiently to reduce toxicity. If stripping occurred, it could have affected the bioavailability of spiked VOCs.

Table B-11 shows the acute toxicity of product condensate under Condition 1. All definitive (multiple concentration) acute toxicity tests under Condition 1 resulted in LC5Os greater than 100 percent. LC50 of greater than 100 percent is the upper sensitivity limit for this test and means that less than 50 percent of the test organisms died during the 40-hour test period. All screening (single concentration) acute toxicity tests under Condition 1 were nontoxic to the freshwater organisms C. dubia and P. Promelas. Nontoxic means that no organisms died after 48-hours exposure to undiluted product condensate. Screening tests were not performed on the marine species C. variegatus and M. bahia.

The LC5Os of leachate feed and product condensate are shown in Figure B-4 to illustrate acute toxicity before and

after treatment in the PO*WW*ER™ system. Only unspiked run 2 and spiked run 2 are shown to compare LC5Os. Acute toxicity was reduced in both spiked and unspiked runs during Condition 1, indicating that the PO*WW*ER™ system removed sources of feed waste toxicity.

Condition 2 tested the acute toxicity of product condensate using the freshwater organisms C. dubia and P. promelas. The temperature, pH, and dissolved oxygen levels used during Condition 1 were also used during Condition 2. However, during Condition 2 tests, sample hardness was not adjusted, and acute toxicity was measured using a hardness level of about 1 mg/L as calcium carbonate, which is the hardness of product condensate produced by the PO*WW*ER™ system.

Table B-12 shows the acute toxicity results, expressed as LC5Os, under Condition 2. The results show greater acute toxicity under Condition 2 than Condition 1, under which hardness for the freshwater organisms was adjusted to between 80 and 100 mg/L as calcium carbonate. Two of
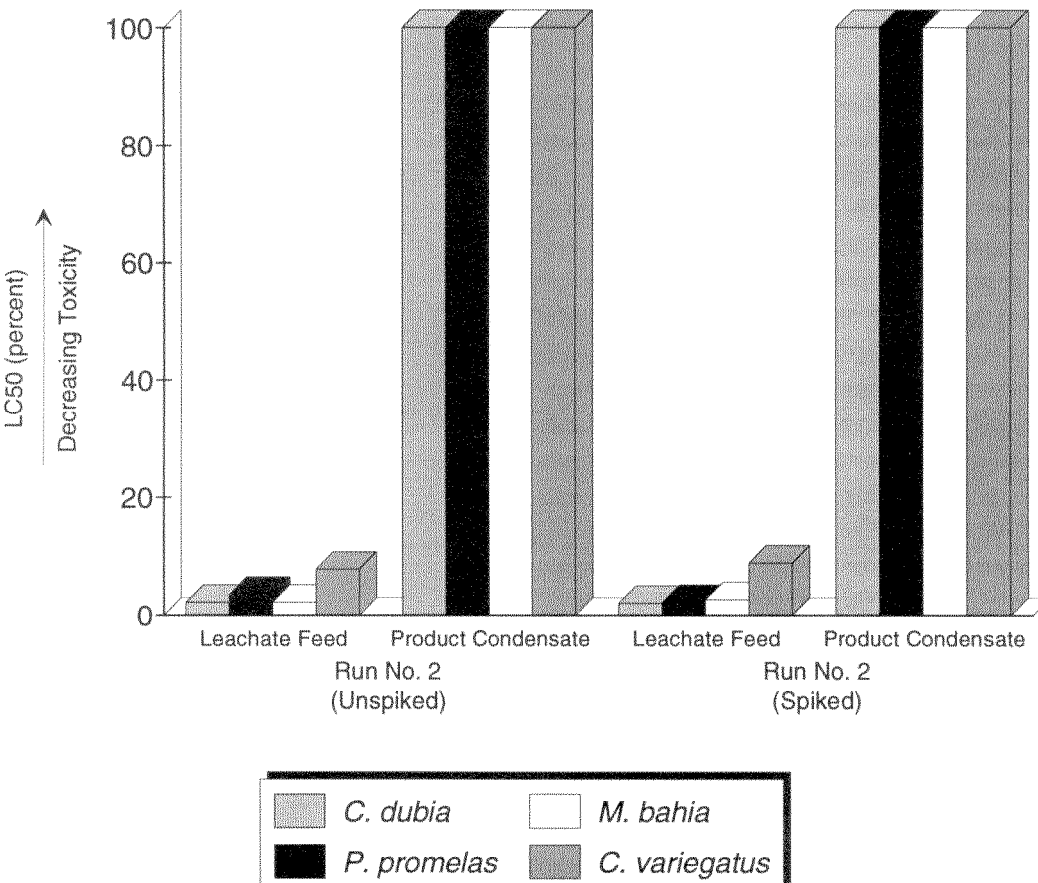

Figure B-4. Acute toxicity of leachate feed and product condensate during unspiked run 2 and spiked run 2—condition 1

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Table B-12. LC50 Values of Product Condensate at Hardness of 1 mg/L as Calcium Carbonate Under Condition 2

Run No.	Organism[a]	
	C. dubia	P. promelas
Unspiked Test Runs		
1	>100[b]	>100
2	>100	18
3	49	>100
Spiked Test Runs		
1	88	>100
2	>100	>100
3	>100	>100

Notes:

[a] M. bahia and C. variegatus were not tested under Condition 2.

[b] >100 = LC50 statistically calculated as greater than 100 percent

the three product condensate samples from the unspiked test runs and one of the three product condensate samples from the spiked test runs were acutely toxic under Condition 2. The LC50 of <u>C. dubia</u> was 49 percent during unspiked run 3 and 88 percent during spiked run 1. Unspiked run 2 resulted in an LC50 value of 18 percent for <u>P. promelas.</u> The remaining runs resulted in LC50 values of greater than 100 percent. These data indicate that product condensate was toxic when tested without adjustment of hardness.

EPA's ambient water quality criteria were used to identify suspected causes of toxicity in product condensate. The concentrations of chemicals and the conditions in product condensate were compared to criteria to protect aquatic life from acute toxicity (acute criteria). The comparison is limited because it does not address the effects of interactions among chemicals and assumes that the 9-hour composite samples used for chemical analysis represent conditions in grab samples used for toxicity tests. Copper was the only constituent in product condensate from unspiked and spiked test runs that exceeded the acute criteria. The remaining metals concentrations were less than their respective criteria. VOC and SVOC concentrations were less than detection levels and were not compared.

More monitoring data would have to be generated to determine with certainty the cause of product condensate acute toxicity during Condition 2. However, these observations generally correspond to the LC50 data in Tables B-11 and B-12, where a toxic effect was found under Condition 2 but not under Condition 1.

In addition to contaminant concentrations, the toxicity of any sample may be affected by conditions such as pH, hardness, and temperature. Temperature and pH measurements taken during sample collection revealed that product condensate discharged from the PO*WW*ER™ system at an average temperature of about 125 °F and at a pH of between 3.8 and 4.3. These conditions may increase acute toxicity. The effects of temperature and pH were not measured during Conditions 1 and 2 toxicity tests. EPA indicates that acute toxicity from elevated temperatures may occur in unacclimated species and that acute toxicity from pH alone may occur when the pH is below 6.0 (EPA, 1991a). The pH can affect an organism's metabolism directly, or it can cause a change in the toxicity of individual parameters by affecting the parameter's bioavailability.

B.3.2 *Summary of Results for Noncritical Parameters*

The following sections discuss the results of the noncritical parameters, including nonvolatile inorganic compounds; oil and grease; TOX and TOC; pH; and TCLP VOCs and SVOCs.

Nonvolatile Inorganic Compounds

Nonvolatile inorganic compounds include metals, TCLP metals, sulfate, nitrate, and chloride. Each of these compounds is discussed below.

Metals

During the unspiked test runs, the total metals concentration in feed waste samples ranged from 4,600 to 5,000 mg/L; in brine samples it ranged from 150,000 to 170,000 mg/L; and in product condensate samples it ranged from 0.04 to 0.18 mg/L. The results show that metals primarily concentrate in the brine, with concentration ratios ranging from 31 to 1 to 35 to 1.

During the spiked test runs, the total metals concentration in feed waste samples ranged from 5,100 to 5,200 mg/L; in brine samples it ranged from 150,000 to 160,000 mg/L; and in product condensate samples it ranged from 0.06 to 0.13 mg/L. The results show that metals concentrate primarily in the brine, with concentration ratios ranging from 29 to 1 to 31 to 1.

TCLP Metals

During the unspiked test runs, TCLP metal concentrations in brine were as follows: (1) arsenic ranged from 34,400 to 79,200 ug/L; (2) barium ranged from less than 10 to 398 µg/L; cadmium ranged from less than 20 to 50.4 µg/L; (3) chromium ranged from 2,600 to 4,070 µg/L;

(4) lead ranged from less than 180 to 203 µg/L; and (5) selenium ranged from 280 to 894 µg/L.

During the spiked test runs, TCLP metal concentrations in brine were as follows: (1) arsenic ranged from 8 1,500 to 103,000 µg/L; (2) barium ranged from 180 to 250 ug/L; (3) cadmium ranged from 618 to 906 µg/L; (4) chromium ranged from 2,490 to 3,270 µg/L; and (5) selenium ranged from 619 to 657 ug/L.

Based on the results of TCLP test for metals, brine, which is an F039-derived hazardous waste, also exhibits the characteristic of a DO04 hazardous waste because it contains TCLP arsenic at concentrations ranging from 34,400 to 103,000 ug/L. These concentrations are greater than the regulatory level of 5,000 ug/L. All other TCLP metals met RCRA regulatory requirements.

Sulfate

During the unspiked test runs, sulfate concentration in feed waste samples ranged from 1,600 to 1,700 mg/L; in brine samples it ranged from 26,000 to 30,000 mg/L; and in product condensate samples it was less than 2 mg/L.

During the spiked test runs, sulfate concentration in feed waste samples ranged from 1,800 to 1,900 mg/L; in brine samples it ranged from 22,000 to 29,000 mg/L; and in product condensate samples it was less than 2 mg/L.

The sulfate concentration ratio, which is defined as the ratio of sulfate concentration in the brine over the sulfate concentration in the feed waste, had an average value of 15.5, almost one half of the TS, chloride, and metals concentration ratio. The reason for the difference could be because sulfate in the brine precipitates as metal sulfate salts, which are deposited in the piping that transfers brine from the evaporator to the brine drum. During the SITE demonstration, this piping became clogged, which supports this hypothesis. Consequently, sulfate concentration in brine is probably underestimated because sampling was done at the brine drum and not immediately after the evaporator.

Nitrate

During the unspiked test runs, the concentration of nitrate in feed waste samples was less than the detection limit of 0.05 mg/L for most samples analyzed. Only the concentration of one feed waste sample was above the detection limit, at a value of 0.095 mg/L. The concentration of nitrate in brine samples was below the detection limit of 5 mg/L. Nitrate was consistently present in all product condensate samples at concentrations ranging from 0.23 to 0.37 mg/L.

During the spiked test runs, the concentration of nitrate in the feed waste was less than the detection limit of 0.05 mg/L for most samples analyzed. Only the concentration of one feed waste sample was above the detection limit, at a value of 2 mg/L. The concentration of nitrate in brine was below the detection limit, which ranged from 0.05 to 0.25 mg/L. Nitrate was consistently present in all product condensate samples at concentrations ranging from 0.44 to 0.68 mg/L. The presence of nitrate in the product condensate is discussed extensively under *pH.*

Chloride

During the unspiked test runs, total chloride concentration in feed waste samples ranged from 4,700 to 4,800 mg/L; in brine samples it ranged from 150,000 to 170,000 mg/L; and in product condensate samples it was less than the detection limit of 1 mg/L. Therefore, chloride concentrations in brine samples had concentration ratios ranging from 32 to 1 to 35 to 1.

During the spiked test runs, the total chloride concentration in feed waste samples was 4,600 mg/L; in brine samples it ranged from 130,000 to 150,000 mg/L; and in product condensate samples it was less than the detection limit of 1 mg/L. Therefore, chloride concentrations in brine samples had concentration ratios ranging from 28 to 1 to 33 to 1.

Chloride was not detected in product condensate samples. During the oxidation of chlorinated organic compounds, HCl may form as a byproduct. Because HCl was detected in noncondensible gas emissions (see Noncondensible Gas Emissions), the results suggest that HCl was formed in the oxidizer. However, because HCl was not detected in the product condensate, results suggest that it was at least partially removed in the scrubber. During the SITE demonstration, the scrubber blowdown was not sampled because of testing limitations imposed by CWM.

pH

The pH of feed waste samples ranged from 8.98 to 9.17 during the unspiked test runs, and from 8.58 to 8.83 during the spiked test runs. The pH of the feed waste was not adjusted during the SITE demonstration. The pH of the brine was measured in samples taken from the second and third unspiked test runs and was found to be 10.8 and 10.9,

respectively. No other samples were available for brine pH measurement because of the small amount of brine wasted. The pH of the product condensateranged from 3.83 to 4.27 during the unspiked test runs and from 4.02 to 4.22 during the spiked test runs. The acidic pH of product condensate could be attributed to the presence of HCl, CO_2, and nitric acid (HNO_3). HCl and CO_2 are usually formed during the catalytic oxidation of chlorinated organic compounds. HNO_3 is formed from the hydrolysis of nitrogen dioxide (NO_2). Both potential factors are discussed below.

Analytical results showed that chloride concentration in the product condensate was less than the detection limit of 1 mg/L during both the unspiked and spiked test runs. HCl was detected in the noncondensible vent gas only during the second and third unspiked runs at concentrations of 48.6 ug/dscm and 247 ug/dscm, respectively. Therefore, during the other SITE demonstration runs, HCl that may have formed in the catalytic oxidizer was effectively removed in the caustic scrubber.

Also, CO_2 is not likely present in the product condensate in significant amounts because of the wet caustic scrubber used before the condenser. Because of the elevated temperature of the product condensate (about 125 °F) and its low pH (about 4), any residual CO_2 is expected to escape through the noncondensible gas vent.

Analytical results show that nitrate was consistently present in product condensate at concentrations ranging from 0.23 to 0.37 mg/L during the unspiked test runs and from 0.44 to 0.68 mg/L during the spiked test runs. Because nitrate concentration in the feed waste was less than the detection limit (see Nitrate), nitrate apparently originated from the catalytic oxidation process. This possibility is further discussed below.

Nitrate could have resulted from the hydrolysis of NO_2. Three sources of nitrogen may contribute to the formation of NO_2 during the oxidation reactions that take place in PO*WW*ER™ catalytic oxidizer: (1) ammonia (NH_3), (2) air, which is an inevitable source in fuel-air reactions and contains molecular nitrogen (N_2) and oxygen (O_2) in a molar ratio of roughly 3.75 to 1, and (3) cyanide (CN-). The bond energy of N≡N in molecular nitrogen is much greater than that of a C-N bond (Wark and Warner, 1981).

The potential formation pathways of NO_2 from the above-mentioned nitrogen sources are presented below.

However, the intermediate reaction steps are outside the scope of this discussion and are not presented.

According to the discussion presented in Section B .3.1, most of the ammonia present in the feed waste was effectively evaporated and presumably oxidized in the catalytic oxidizer. Ammonia oxidizes in air according to the following reaction (Cotton and Wilkinson, 1976):

$$\textbf{4NH}_3 + 3O, \leftrightarrow \textbf{2N}_2 + \textbf{6H}_2\textbf{O} \tag{B-2}$$
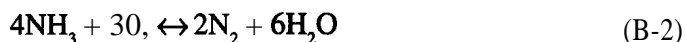
In the presence of a catalyst, some ammonia oxidizes according to the following reaction:

$$\textbf{4NH}_3 + 5O, \leftrightarrow \textbf{4NO} + \textbf{6H}_2\textbf{O} \tag{B-3}$$
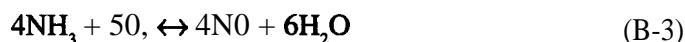
This reaction leads to the synthesis of nitrogen monoxide (NO), which reacts with excess O_2 to produce NO_2, and the mixed bxides that can be absorbed in water to form HNO_3:

$$2NO + O_2 \leftrightarrow 2NO_2 \tag{B-4}$$

$$\textbf{3NO}_2 + \textbf{H}_2\textbf{O} \leftrightarrow \textbf{2HNO}_3 + \text{NO} \tag{B-5}$$

The formation of NO_2 from NO is rate limited. However, the equilibrium rate constant for the oxidation of NO to NO_2 increases dramatically when the temperature decreases in the presence of excess oxygen. Therefore, it is very likely that the oxidation of NO to NO_2 occurs instantly in the condenser in the presence of O_2.

HNO_3 also results from NO_2 produced from the oxidation of nitrogen present in the air used as oxidation fuel according to the reactions below (Wark and Warner, 1981):

$$\textbf{N}_2 + \textbf{O}_2 \leftrightarrow \textbf{2NO} \tag{B-6}$$

$$\text{NO} + \frac{1}{2}\textbf{O}_2 \leftrightarrow \text{NO}_2 \tag{B-7}$$

Some of the cyanide originally present in feed waste is evaporated and is oxidized in the catalytic oxidizer to form CO_2 and N_2. In the presence of excess air, $\textbf{N}_2$ oxidizes to form NO_2 according to equations B-6 and B-7. NO_2 in turn hydrolyzes in water to form HNO_3 according to Equation B-5.

The results show that NH_3, N_2, and CN- are sources of nitrogen, which oxidize in the catalytic oxidizer to form

NO_2, which in turn hydrolyzes in water to produce HNO_3. HNO_3 is a strong acid that dissociates completely in water according to the following reaction:

$$HNO_3 \leftrightarrow H' + NO_3 \qquad \text{(B-8)}$$

Figure B-5 presents the product condensate pH values predicted for the scenario discussed above for the formation of HNO_3. Figure B-5 also presents the median measured pH values of the product condensate. The predicted and measured pH values are similar and also follow the same trend, which supports this scenario.

In order to produce product condensate with neutral pH, an NO_2 absorption step is required before the condensation step. NO_2 can be absorbed by water, hydroxide, and carbonate solutions; sulfuric acid; organic solutions; and molten alkali carbonates and hydroxides (Wark and Warner, 1981).

Oil and Grease, TOX, and TOC

During the unspiked test runs, oil and grease concentration in feed waste samples ranged from 550 to 730 mg/L and in brine samples from 330 to 1,400 mg/L, resulting in an average concentration ratio of 1.5 to 1.

During the spiked test runs, oil and grease concentration in feed waste samples ranged from 430 to 540 mg/L and in brine samples from 1,800 to 2,200 mg/L, resulting in an average concentration ratio of 4.2 to 1.

Because the TS concentration ratio is about 32 to 1, the results indicate that some of the material contributing to oil and grease is also removed during treatment of landfill leachate in the PO*WW*ER™ system. During theunspiked test runs, oil and grease removal efficiency ranged from 88 to 98 percent. During the spiked test runs, oil and grease removal efficiency ranged from 76 to 78 percent.

During unspiked test runs, TOX concentration in feed waste samples ranged from 144 to 155 mg/L; in brine samples it ranged from 2,780 to 5,650 mg/L; and in product condensate samples from 0.049 to 0.077 mg/L. Therefore, TOX primarily concentrates in the brine, with an average concentration ratio of 28 to 1. During the spiked test runs, TOX concentration in feed waste samples ranged from 142
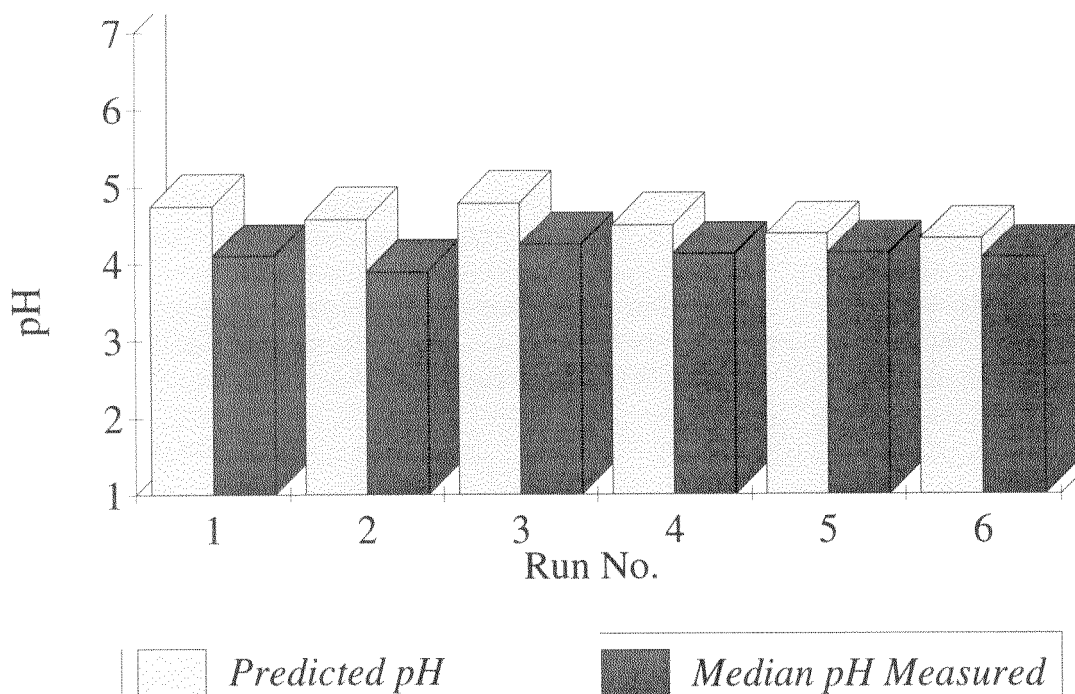
Figure B-5. Product condensate pH predicted and median pH measured during unspiked and spiked test runs.

Note: Runs 1 through 3 were conducted with unspiked landfill leachate, and
Runs 4 through 6 were conducted with spiked landfill leachate.

to 170 mg/L; in brine samples it ranged from 4,640 to 5,270 mg/L; and in product condensate samples it ranged from 0.050 to 0.059 mg/L. Therefore, TOX primarily concentrates in the brine, with an average concentration ratio of 32 to 1.

The TOC concentration in the feed waste was determined reliably only during the second unspiked test run and during the first spiked test run. Therefore, only these results are discussed.

During the unspiked test run, TOC in the feed waste sample was 33,600 mg/L; in the brine sample it was 41,300 mg/L; and in the product condensate sample it was less than 0.5 mg/L. The TOC evaporation efficiency was about 94 percent.

During the spiked test run, TOC in the feed waste sample was 34,500 mg/L; in the brine sample it was 51,800 mg/L; and in the product condensate sample it was 2.98 mg/L. The TOC evaporation efficiency was about 93 percent. The TOC evaporation efficiency did not change significantly during the spiked test runs, which is when the total contaminant loading increased.

TCLP VOCs and SVOCs

During the unspiked test runs, TCLP VOCs in brine were less than the detection limits, which were less than 100 ug/L for most compounds. During the spiked test runs, the TCLP VOCs were as follows: (1) acetone ranged from 140 to 180 ug/L, (2) methylene chloride ranged from 84 to 140 µg/L, (3) PCE ranged from 27 to 68 ug/L, and (4) toluene ranged from 25 to 51 ug/L.

During the unspiked test runs, the only TCLP SVOC detected in brine above the detection limit was benzoic acid, which ranged from 110,000 to 340,000 ug/L. During the spiked test runs, TCLP SVOCs were as follows: benzoic acid ranged from 350,000 to 470,000 ug/L and bis-(2-ethylhexyl) phthalate ranged from 6,200 to less than 10,000 ug/L.

The results show that total contaminant loading, which increased during the spiked test runs, resulted in increased concentrations of TCLP VOCs. Both TCLP VOCs and SVOCs met RCRA TCLP standards.

B.4 References

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Appendix C
Case Study Results

During the development of the **PO*WW*ER™** technology, Chemical Waste Management, Inc. (CWM), performed several test runs on various wastewaters. The test runs were conducted at the **PO*WW*ER™** pilot-scale (pilot) plant located at the Lake Charles Treatment Center (LCTC) site. The key performance parameters investigated in these test runs were (1) concentration ratio, (2) boiling point rise in the evaporator, (3) heat transfer coefficient, (4) oxidation efficiency, and (5) product condensate quality. The results of these test runs are summarized below as individual case studies. However, results of the boiling point rise in the evaporator and heat transfer coefficients are not reported because CWM considers the information proprietary.

In one case study, landfill leachate was treated in the **PO*WW*ER™** pilot plant. The landfill leachate contained total organic carbon (TOC) at concentrations ranging from 980 to 4,000 milligrams per liter (mg/L) and total dissolved solids (TDS) at 2 percent. The landfill leachate pH ranged from 9 to 11. The results show that a concentration ratio of 40 to 1 was achieved. The brine contained 63 percent total solids (TS) and TOC concentrations ranging from 15,000 to 42,000 mg/L. The pH of the product condensate ranged from 6 to 9.

In a second case study, landfill leachate was also treated in the **PO*WW*ER™** pilot plant. The landfill leachate contained TOC ranging from 730 to 3,100 mg/L and TDS at 2 percent. The pH of the landfill leachate ranged from 6.7 to 11.9. A concentration ratio of 40 to 1 was achieved in the evaporator. The brine contained 49.5 percent TS, All metals in the product condensate were at concentrations below National Pollutant Discharge Elimination System(NPDES) storm water discharge limits.

In a third case study, landfill leachate spiked with ammonia was treated in the **PO*WW*ER™** pilot plant. The landfill leachate contained TOC ranging from 850 to 2,850 mg/L; ammonia ranging from75 to 2,880 mg/L; and TDS at 1.3 percent. The landfill leachate pH ranged from 9 to 11. A concentration ratio of 40 to 1 was achieved. The brine contained 50 to 70 percent TS and 4 to 8.5 percent TOC. The ammonia was effectively removed from the brine. In the product condensate, both metals and organics were removed to below NPDES storm water discharge limits without further treatment.

In a fourth case study, landfill leachate spiked with methanol was treated. The landfill leachate contained TOC at 540 to 2,300 mg/L; methanol at 500 to 5,000 mg/L; and TDS at 1.3 percent. The pH of the landfill leachate ranged from 2.2 to 9.4. A concentration ratio of 40 to 1 was achieved. The brine contained 46 to 52 percent **TS .** Methanol was effectively evaporated and successfully oxidized. A removal efficiency of 98 percent was achieved. Ammonia concentration in the brine was less than the detection limit of 5 mg/L.

In a fifth case study, landfill leachate spiked with 100 mg/L of each of the following chemicals was treated: acetone, carbon disullide, chlorobenzene, methanol, methyl ethyl ketone, methylene chloride, nitrobenzene, toluene, and trichloroethylene. TDS concentration was 1.3 percent and pH ranged from 7.5 to 11.2. The results show that a concentration ratio of 38 to 1 was achieved in the evaporator. The brine contained 49 percent TS. All spiking chemicals were effectively stripped from the brine. Only the nonvolatile organics originally present in the landfill leachate remained. Oxidation efficiencies of greater than 99 percent were achieved for all spiking organics.

In a sixth case study, landfill leachate was spiked with ammonia and methanol at concentrations of 0.1 percent ammonia and 3 percent methanol, respectively. At pH 11, the ammoniaevaporation efficiency was significantly higher than at a pH ranging from 7 to 8. The methanol was removed from the brine.

In a seventh case study, lagoon water was treated in the **PO*WW*ER**™ pilot plant. The lagoon water contained TOC ranging from 280 to 1,500 mg/L and TDS at less than 1 percent. The lagoon pH was adjusted to 12. A concentration ratio of 50 to 1 was achieved. The brine contained 5 1 percent **TS**. The concentration of TOC in the product condensate without oxidation ranged from 80 to 145 mg/L. The oxidation efficiency ranged from 90 to 97 percent.

In an eighth case study, fuels decant water was treated. The fuels decant water contained 2 percent TOC and had pH of 8. A concentration of 42 to 1 was achieved in the evaporator. The TOC removal efficiency was greater than 99 percent.

In a ninth case study, well water spiked with cyanide at 139 mg/L was treated. The well water was acidified to cause the release of hydrogen cyanide (HCN) gas. Cyanide was evaporated from the brine to below detection limits. The cyanide level in the product condensate was also below detection limits.

In a tenth case study, oil emulsion wastewater was treated in abench-scale system. Theoilemulsion wastewater contained 4,750 mg/L of TOC and 130 mg/L of ammonia; had a pH of 8.8; and contained 14,000 mg/L TS. The TS concentration ratio achieved was 35 to 1. The oxidized product condensate contained 1.5 mg/L TOC, 0.1 mg/L ammonia, and 55 mg/L chloride and had a pH of 3.1.

In an eleventh case study, wastewater contaminated with nitrogen-containing organic compounds and cyanide was treated in the **PO*WW*ER**™ pilot plant. The feed waste pH was not adjusted. Antifoaming agent (EP-530) was added on an as-needed basis. The feed waste processing rate was 0.2 gallons per minute (gpm). The scrubber operated with water alone. The feed waste had a pH ranging from 4 to 4.42; ammonia-nitrogen (NH,-N) ranging from 13,000 to 15,400 mg/L; sulfate ranging from 45,000 to 58,200 mg/L; TOC ranging from 20,500 to 36,300 mg/L;

cyanide ranging from 205 to 1,613 mg/L; and nitrogen-containing organics content from 50 to 11,000 mg/L. The brine had a pH of 4.31; 68,500 mg/l NH,-N; sulfate at 306,300 mg/L; TOC at 84,000 mg/L; cyanide at 124 mg/L; and nitrogen-containing organics ranging from 77 to 456 mg/L. The TS concentration in the feed ranged from 8.57 to 10.1 percent. The TS in the brine ranged from 28 to 80 percent. The cyanide concentration in the product condensate ranged from 0.2 to 51 mg/L, representing removal efficiencies ranging from 96.9 to 99.99 percent. Oxidation efficiencies ranged from 93.5 to 99.96 percent. NH,-N in product condensate ranged from less than 5 to 210 mg/L, representing removal efficiencies ranging from 91.6 to greater than 99.6 percent. Oxidation efficiencies ranged from 83.8 to greater than 99.6 percent.

During the eleventh case study, the evaporator heat exchanger heat transfer coefficients were also determined. Under certain conditions, the physical-chemical characteristics of the brine may have a fouling effect on the heat transfer surfaces. As the TS concentration in the brine increases, the solids in the boiling brine provide a significant scouring action and thus clean the evaporator surface. Periodic system cleaning may be required to maintain high heat transfer coefficients.

Based on the case studies discussed above, CWM concludes that product condensate from the **PO*WW*ER**™ system meets stringent discharge standards and chronic toxicity testing. The product condensate may be reused as cooling tower make-up water, boiler make-up water, or process feed water. In addition, CWM states that the **PO*WW*ER**™ product condensate quality is as follows: (1) TDS less than 25 mg/L, (2) TOC less than 10 mg/L, (3) suspended solids less than 1 mg/L, and (4) hardness less than 1 mg/L. According to CWM, the product condensate quality that can be achieved by the **PO*WW*ER**™ system exceeds requirements for typical boiler make-up water and typical cooling tower make-up water.